Queensland
Government

Department of
Environment and
Heritage Protection

Ref CR72122

31/10/2016

Standards Information Service
Standards Australia
Level 10, The Exchange Centre
20 Bridge Street
Sydney NSW 2001

Dear Sir / Madam

The Queensland Department of Environment and Heritage Protection (the department) has been investigating complaints about blasting at a quarry in Mt Coot-tha, an inner suburb of Brisbane in Queensland Australia. Complainants allege that blasting has impacted residential dwellings which have been constructed in recent years in relatively close proximity to the quarry.

Australian Standard 2187.2 "*Explosives- Storage and Use, Part 2: Use of Explosives*" has been referred to by consulting professionals, the community and the department at various times during the complaint investigation. Most recently, the community has raised concern that AS2187.2 does not provide guidance in relation to impacts from blasting over an extended period of time, nor in upper levels of 2 and 3 storey residential dwellings.

Whilst the department notes that Table J4.5(a) mentions sensitive sites and includes guidance for blasting that exceeds 12 months or more than 20 blasts, members of the community are concerned that vibrations from quarry blasting that exceeds 10 years and hundreds of blasts may have implications for structural integrity of homes and amplification of vibration and overpressure, even when ground vibration is within the 5 - 10mm/s spectrum as measured by a professional consulting firm.

The department understands that members of the Mt Coo-tha community are preparing a submission to Standards Australia. Whilst the department is not seeking to endorse the community submission, the department does note that clear guidance regarding long term blasting and impacts within upper levels of 2 and 3 storey residential premises is worthy of consideration by Standards Australia within AS2187.2.

Level 4
33 King Street Caboolture
PO Box 808 Caboolture
Queensland 4510 Australia
Telephone + 5316 8403
Page 1 of 2
Website www.ehp.qld.gov.au
ABN 46 640 294 485

Should you have any further enquiries, please contact me on telephone 5316 8403.

Yours sincerely

sch4p4(6) Personal Information [redacted]

Matt Karle
Compliance Delivery Manager, South Queensland Compliance – Brisbane Moreton Bay
Environmental Services and Regulation
Department of Environment and Heritage Protection

Work Request
Technical Support Team

Date of request: 17.8.2016

Requesting Officer: Matt Karle

Phone Number: 5316 8403

Office/Region: Brisbane Moreton Compliance

Date Response is Required: ASAP please

Email Address for Response: matt.karle@ehp.qld.gov.au

Manager: Matt Karle

Manager's Phone Number: 5316 8403

Manager's Approval of Request: Yes

Proponent / Company / Person / Project: Brisbane City Council – Mt Coot-tha Quarry

Site/Location (if relevant): Mt Coot-tha , Mount Coot-tha Road, Toowong

File Number and Doc# : 101/0005158 *This is used to locate any specific EDOCs files that are associated with this work request.*

Request Type

☐ EIS / High Risk Assessment *(Requires Director to approve request is for high risk assessment)*
Has director approval been given? Yes / No
☒ Compliance
☐ Policy Advice

Issue Type(s)
Please delete all bar relevant issues

Noise

Support Category
Please delete all bar relevant category

Compliance Assessment

EA Number *(if relevant)*: EPPR00447313

Details of Activity/Issue: Blasting Noise.

Nature of assistance requested (describe): Brisbane City Council operates the Mt Coot-tha Quarry under Permit number EPPR00447313. Blasting at the Quarry (hard rock) occurs several times a month and is a growing concern for nearby residents. The noise schedule is attached at Attachment 1.

Recent blasting resulted in a ground vibration level of 10.4mm/s and 109.5dB(A) overpressure. The blast 'noise' was also measured by the primary complainant using a hired noise meter from NV Engineers set up inside the complainant's residence on ground floor, which is concrete slab.

The complainant appears to be alleging that the noise meter inside the complainants residence measured some pulse noises several seconds AFTER the blast, and according to the complainants emails is raising allegations that the noise measured AFTER the blast IS NOT part of the blast overpressure and is therefore an exceedence of the Background plus 5 requirements of the EA and that the noise measured AFTER the blast is worse than the initial blast and demonstrates damage risk to property.

The material submitted by the complainant (Several other attachments) includes an initial email with attachments including results downloaded from the hired noise meter as well as from the Quarry Consultant, and a 2nd email wherein the complainant makes allegations about the structural impact of the blasting. Specifically, it seems the complaint makes inferences about measurements 5 and 10 seconds after the blast and what it means for his residence. Wording including:

> *On the 3rd August, the sound levels that I recorded were caused by the building vibrating in accordance with the underground blast vibrations hitting the footings of our building and causing the building to vibrate long after the overpressure sound had dissipated. Furthermore, if the test was repeated, we expect that the recorded results would be similar and proportional to the current blast strength.*
>
> *Hence the sound inside our building (as well as in all other similar buildings close to the blast zone founded in the same bedrock as that being mined), cannot be considered as overpressure sound because the time period is vastly different.*
>
> *The extended time span of our building vibration is in line with Seismic Event Theory which states that the secondary vibration of a building is often much worse than that from the initial seismic vibration and it is actually the secondary vibration which usually destroys the buildings (as advised by our project RPEQ Civil Engineer).*

A review of the submissions by the complainant and advice as to whether the noise measured AFTER the blast can be linked to structural risk or permit exceedance is requested.

For guidance, the requesting officer is of the view that:

- Pulses measured AFTER the blast are likely to be reflections from the blast; and
- Hence the pulses AFTER the blast are related to the blast and are not part of the ordinary noise emission limits of BG plus 5; and
- It would appear the complainant is identifying the pulses AFTER the blast as exceeding BG+5 however the complainant is looking at LnPk (or thereabouts) measurements rather than the statistical LAmaxadjT as prescribed in the EA;
- The vibration and overblast measured all comply with the limit in the EA;
- The vibration limits are below British Standard limits for potential cosmetic damage to light duty residential premises, including the blast vibration and overpressure as well as any reflections recorded on the hired meter.

The requesting officer is requesting advice regarding the validity of the claims made by the complainant, and the validity of the above views of the requesting officer.

Note: Please attach relevant files to request or state EDOCS items number. Every effort will be made to accommodate requests.

Precedence is given to statutory timeframes and environmental issues of an urgent nature and some negotiation of timeframes may be required in circumstances of high workloads.

Officers are advised that you will be required to provide feedback on the Technical Specialist and the content of their work after <u>every</u> work request.

Please return completed forms to: **technicalsupport@ehp.qld.gov.au**

Technical Support Response

This section is to be filled out by the Technical Specialist only. This document will then be sent back to you with the response to the technical support work request shown here.

Date of Technical Response: **26th August 2016**

Requesting Officer: **Matt Karle**

Technical Specialist / Principal Technical Officer: **Antoine David**

Response to Technical Support Request:
EHP jurisdiction is for the nuisance of noise and vibration onto people so to keep their environmental values. EHP has no jurisdiction onto building. However I can say that the thresholds for crack to develop in building due to blasting is an order of magnitude higher than the limit EHP set for vibration to levels.

Minor cracks would be expected starting above 20mm/s to 50mm/s and expected cracks would be expected at vibration levels of 100m/s

Given vibration limits are normally exceeded before blast overpressure, given the blasting engineer is trying to direct all blast energy in rock fracture, this is the primary focus. However should the blast engineer miscalculate, the overpressure also could generate damage. Such damage would not occur below 133dB lin Peak, and window damage expected above 140 dB lin Peak

10.4mm/s is only a 0.4 mm/s exceedance and 109dB Lin Peak is within the criteria

No allegation to crack may be expected.

Attachments? Please list: **20160826_Matt Karle_MtCotha_Part 2 of 2**

Disclaimer:
Any opinions, advice or comments provided in this memo (i.e. the 'Technical Support Response') or associated attachments or emails should not be used as a part of legal proceedings or expert statements. Please advise the Technical Support Manager and Specialist immediately if this response may be used in relation to legal proceedings.

Technical Support responses are based on the information provided by the requesting officer. Although the information provided will be cross-checked and verified wherever possible, Technical Support cannot be held liable for their interpretations based on incorrect, inaccurate, incomplete or otherwise invalid information, nor for any subsequent decisions or actions made by the requesting officer or delegate that was based on misinformed responses.

Saving:
Could all Technical Specialists please save their response in their allocated folder with the request date first and the requesting officers name. i.e. ***20160315_Officer Name****. Folders are located here.*

Please note any attachments on this response form and attach it when saving the document in your allocated folder. i.e. ***20160315_Officer Name_1 of 2*** *and* ***20160315_Officer Name_2 of 2.***

Technical Support answer to request 17th August 2016 in regard to complaint of Mt Cootha Blasting activity

File Number 101/00051158

The first point is that the measurement started of 109.5dBA is compliant outside the property and by definition the proponent complies with the noise criteria.

The second point is that for blasting we do not make noise measurement inside properties. A pulse noise measured inside will have reverberation and echoes from the pulse bouncing around the various walls of the room it is being measured. Those echoes will be lower that the initial pulse.

The third point is that the sound overpressure is not responsible for crack but the ground vibration

The ground vibration as illustrated in the annexe of this document and also in AS 2187.2 2006 Appendix J.

Appendix J show that the vibration required for cosmetic damage is an order of magnitude higher that 10.4 mm/s in table J4.4.2.1 reproduced below together with associated corresponding Figure J4.4.2.1

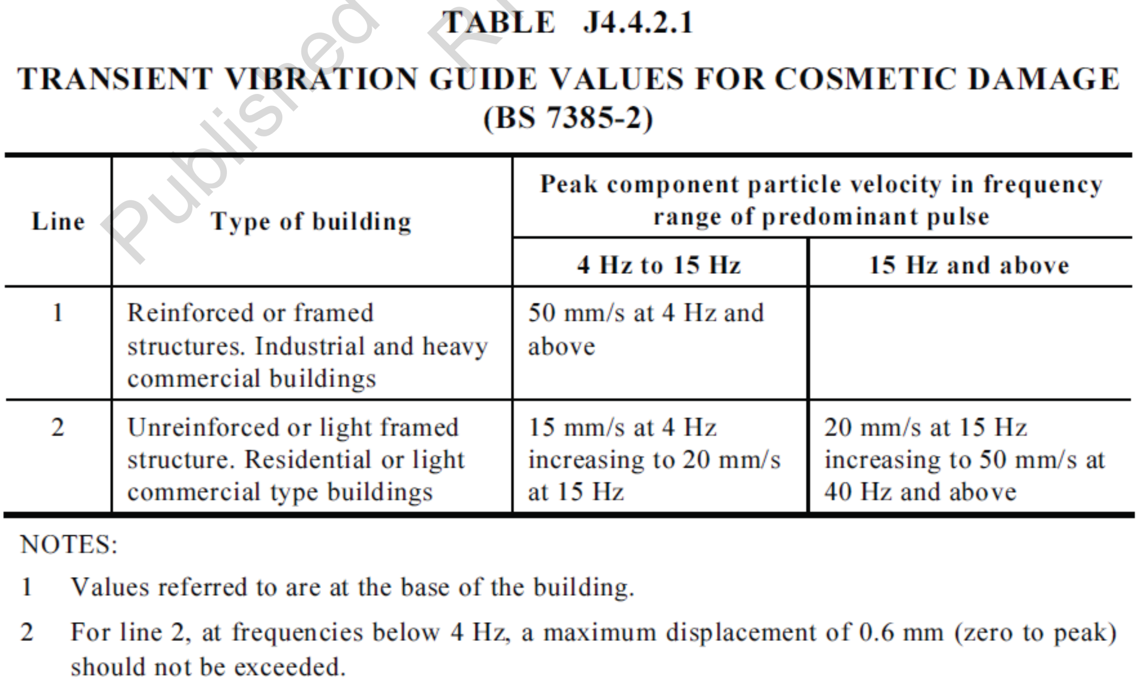

TABLE J4.4.2.1

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.

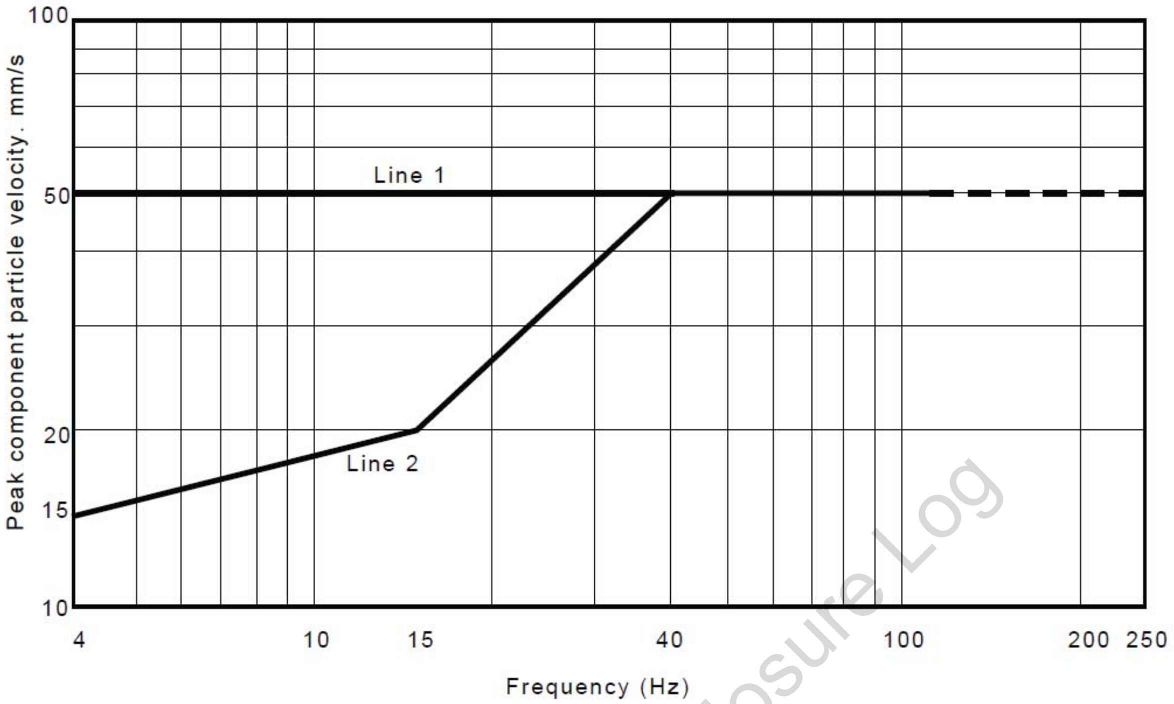

FIGURE J4.4.2.1 TRANSIENT VIBRATION GUIDE VALUES FOR COSMETIC DAMAGE (BS 7385-2)

As can be seen from information selected from Appendix J the allegation from cracks do not match the recorded vibration levels.

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.

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.

J5.3 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.

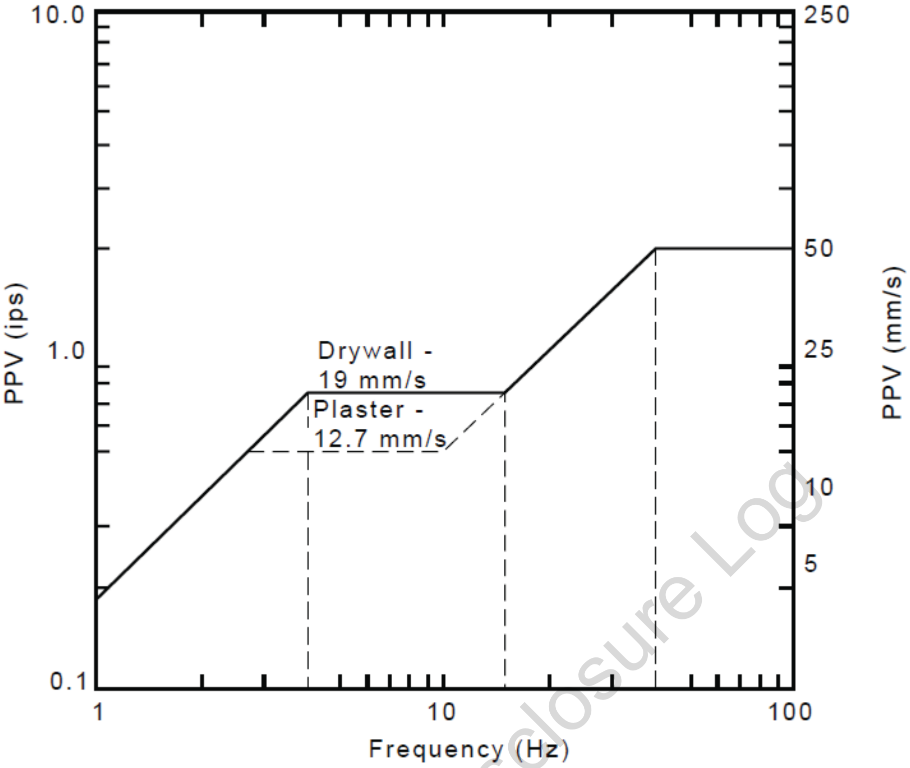

FIGURE J4.4.2.2 USBM 'SAFE' BLASTING VIBRATION LEVEL CRITERIA

USBM damage classifications are shown in Table J4.4.2.3.

ANNEXE

Annexe document to illustrate other documents indicating safe vibration limits from blasting onto structure

From “Effect of blasting on infrastructure” by Alan Richard, Adrian More ACARP project C14057 20/10/2008

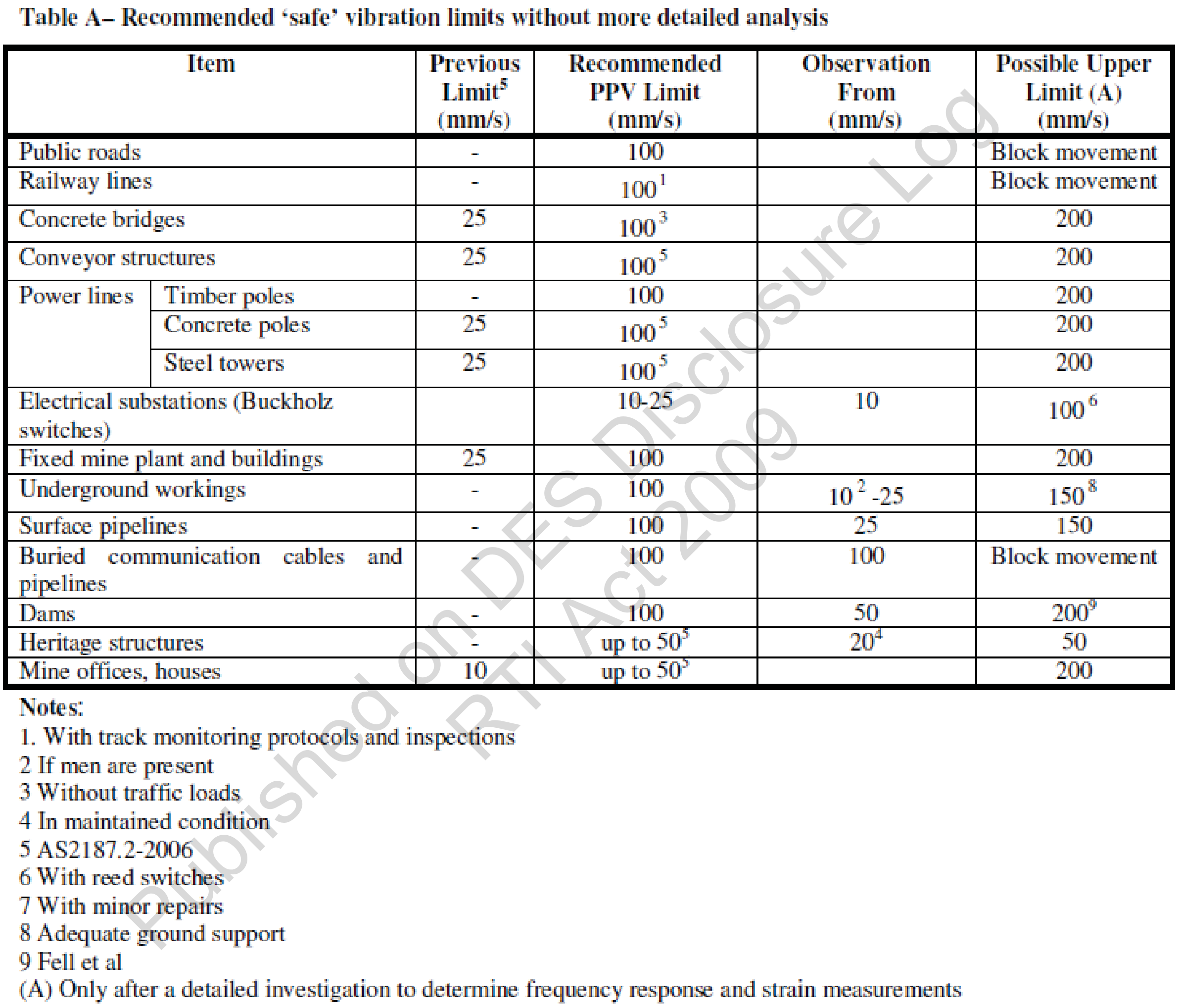

Table A– Recommended ‘safe’ vibration limits without more detailed analysis

Item		Previous Limit[5] (mm/s)	Recommended PPV Limit (mm/s)	Observation From (mm/s)	Possible Upper Limit (A) (mm/s)
Public roads		-	100		Block movement
Railway lines		-	100[1]		Block movement
Concrete bridges		25	100[3]		200
Conveyor structures		25	100[5]		200
Power lines	Timber poles	-	100		200
	Concrete poles	25	100[5]		200
	Steel towers	25	100[5]		200
Electrical substations (Buckholz switches)			10-25	10	100[6]
Fixed mine plant and buildings		25	100		200
Underground workings		-	100	10[2]-25	150[8]
Surface pipelines		-	100	25	150
Buried communication cables and pipelines		-	100	100	Block movement
Dams		-	100	50	200[9]
Heritage structures		-	up to 50[5]	20[4]	50
Mine offices, houses		10	up to 50[5]		200

Notes:
1. With track monitoring protocols and inspections
2 If men are present
3 Without traffic loads
4 In maintained condition
5 AS2187.2-2006
6 With reed switches
7 With minor repairs
8 Adequate ground support
9 Fell et al
(A) Only after a detailed investigation to determine frequency response and strain measurements

From Evaluation of blast-induced vibration effects on structures Joo K.H et al. Transactions of the 14th International Conference on structural Mechanics in Reactor Technology (SMIRT 14), Lyon, France, August 1997

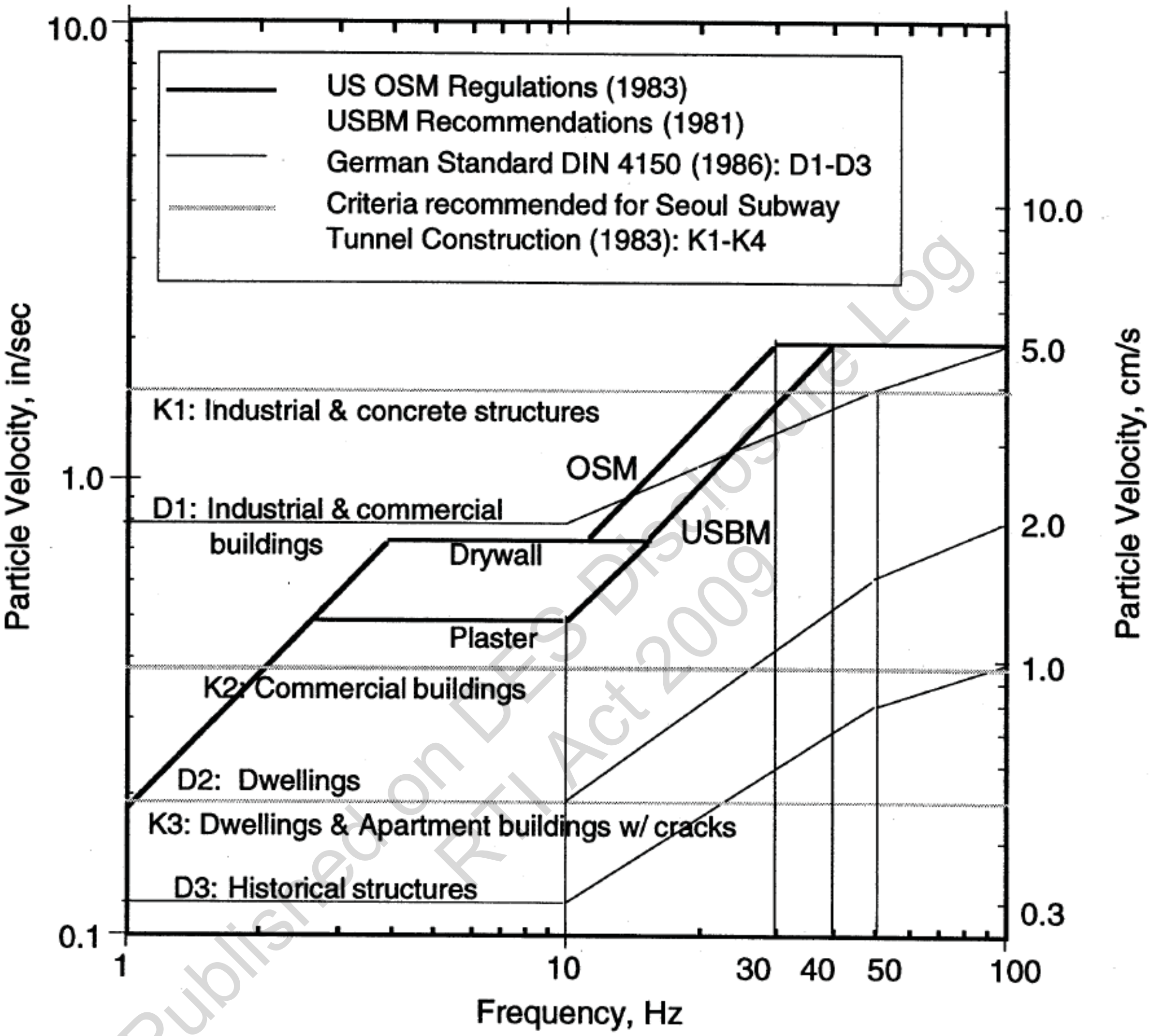

Figure 1. Comparison of safe criteria on blast vibration

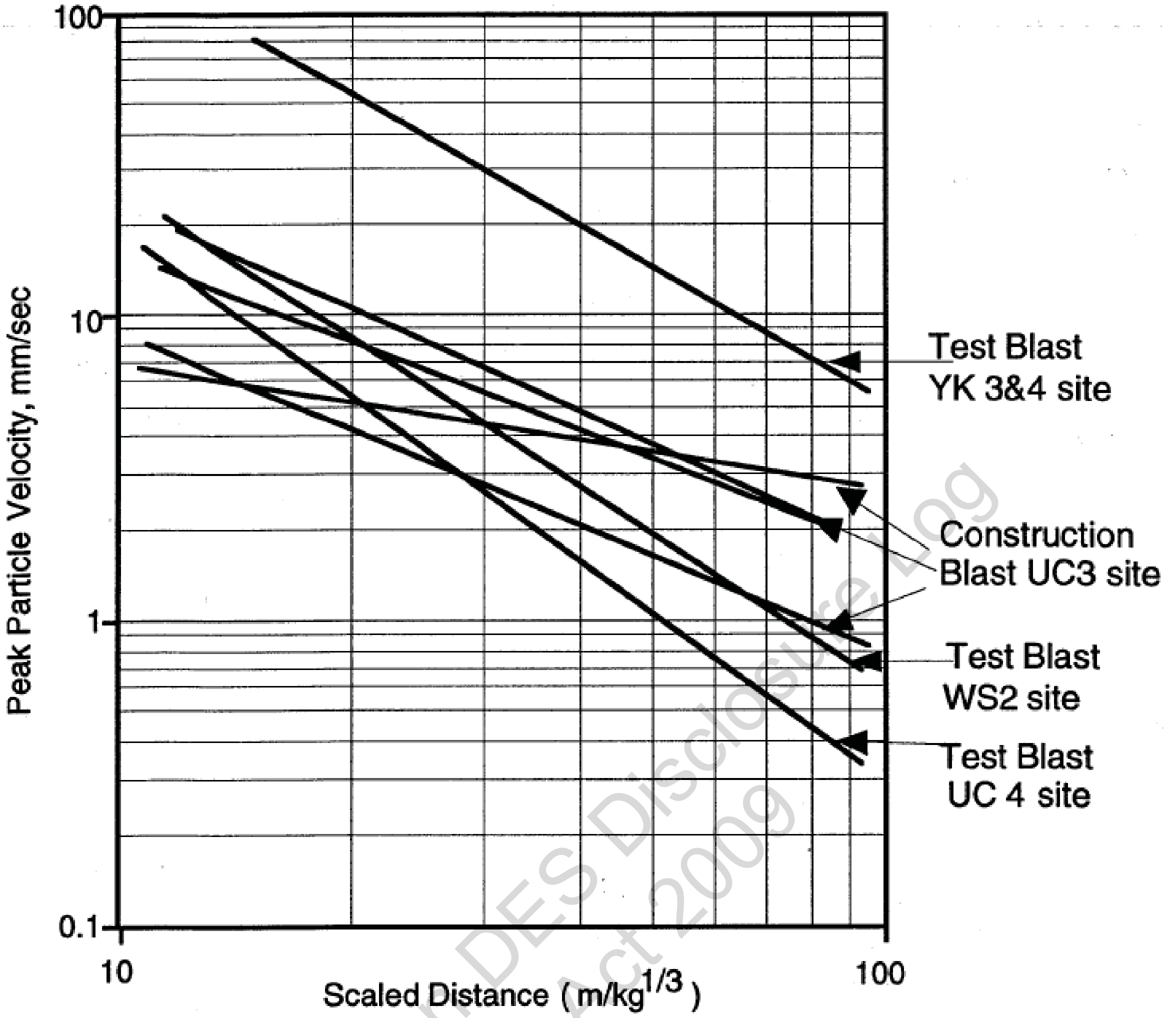

Figure 2. Peak particle velocity vs. scaled distance

From Reducing the environmental effect of aggregate quarrying dust, noise and vibration, William Birch and Hugh Datson, University of Leeds and Ian Lowndes, University of Nottingham

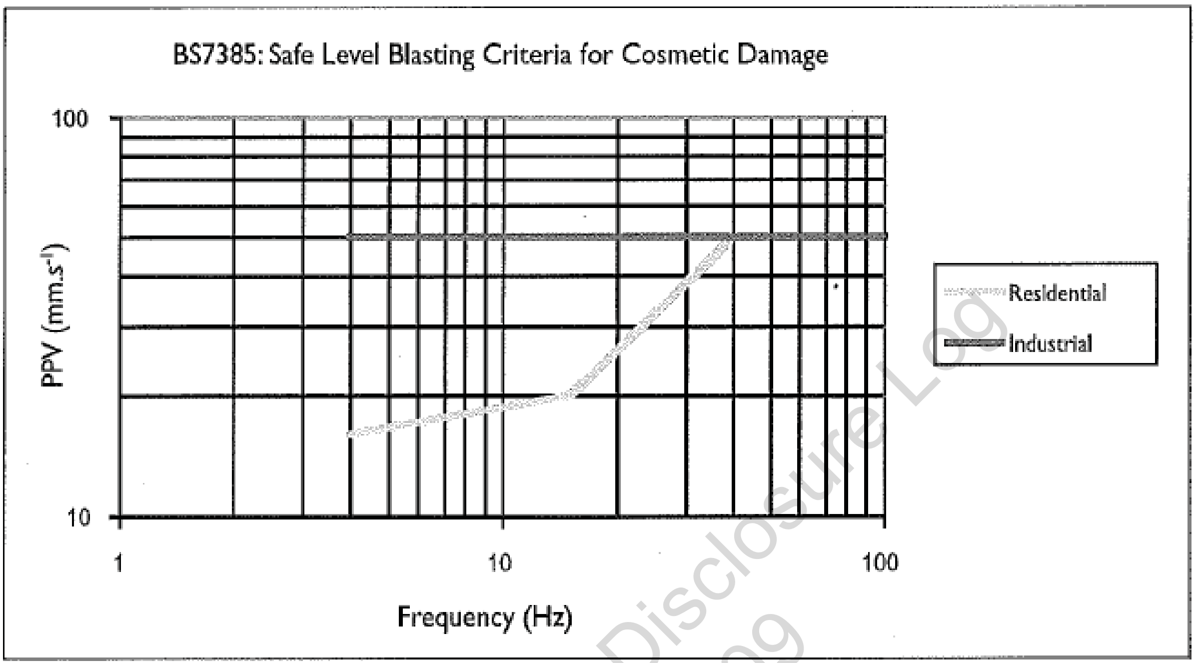

Figure 1.11 Illustration of Safe Blasting Criteria for Cosmetic Damage produced from BS7385 Part 2

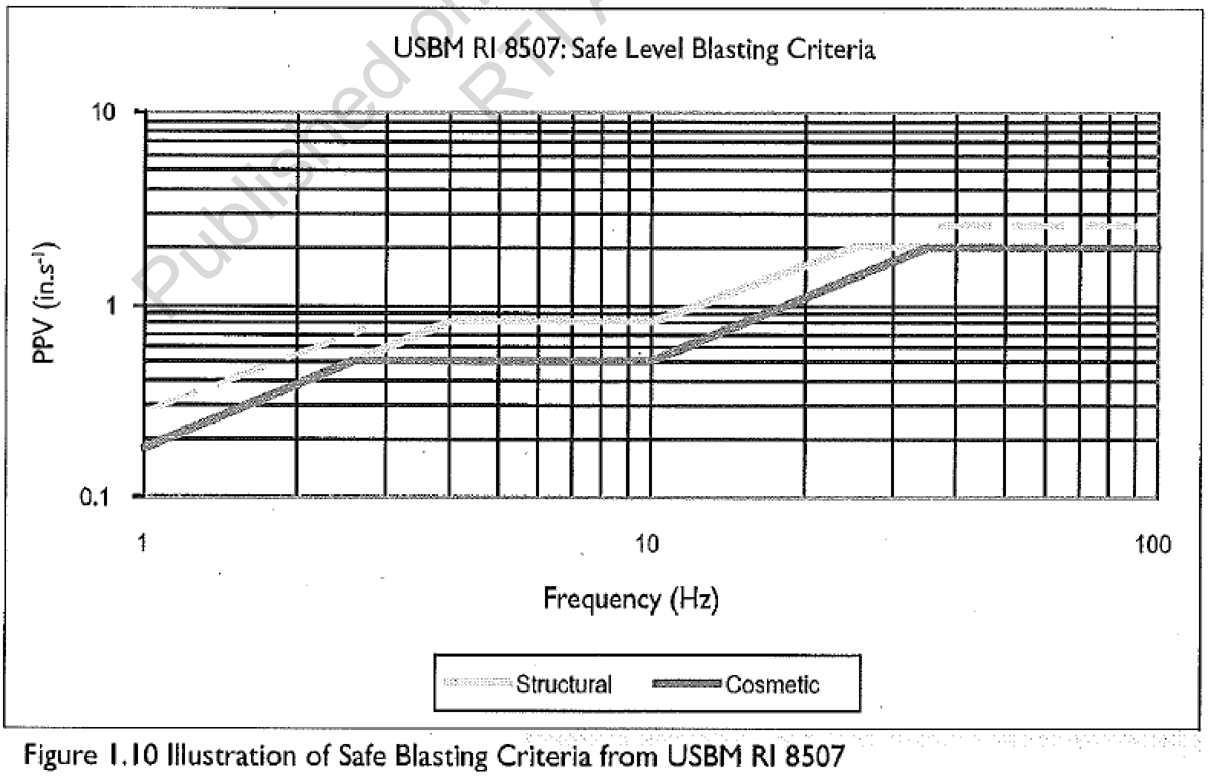

Figure 1.10 Illustration of Safe Blasting Criteria from USBM RI 8507

From: KARLE Matt [Matt.Karle@des.qld.gov.au]
Sent: Thursday, 27 October 2016 10:15 AM
To: ROWE Sarah
Subject: Mt Coot-tha Quarry

For eDOCS please.

Matt Karle
Compliance Delivery Manager, South Queensland Compliance – Brisbane Moreton Bay
Environmental Services and Regulation
Department of Environment and Heritage Protection

P 07 5316 8403
33 King Street, Caboolture Qld 4510

From: CONNOR Andrew
Sent: Thursday, 27 October 2016 10:09 AM
To: KARLE Matt <Matt.Karle@ehp.qld.gov.au>
Subject: FW:

FYI

Andrew Connor
Executive Director
Industry, Development & South Queensland Compliance
Environmental Services and Regulation
Department of Environment and Heritage Protection

P 07 3330 6335
Level 8, 400 George Street, Brisbane QLD 4000
GPO Box 2454, Brisbane QLD 4001

From: CONNOR Andrew
Sent: Thursday, 27 October 2016 10:09 AM
To: sch4p4(6) Persor
Cc: Mount.Coot-tha@parliament.qld.gov.au
Subject: RE:

Dear sch4p4(

Thank you for your email. I assure you that the Department of Environment and Heritage Protection (EHP) is carefully considering its approach to this matter and our officers are currently drafting correspondence outlining the situation at Mt Coot-tha with an intention to send it to Standards Australia in support of a future review of AS2187.

To be clear, EHP has not formed a view that AS2187 is inadequate in the context of applying blast limits to protect human comfort, which is what EHP's conditions are based on. EHP noise specialists have advised me that the threshold for which cracks may appear in a building is an order of magnitude higher than the value set for the wellbeing for humans, for which EHP has jurisdiction.

Notwithstanding this, EHP does agree that the Mt Coot-tha Residents Amendment Proposal to Standards Australia includes points worthy of consideration in a review by that body. Specifically, a consideration of the cumulative number of blasts an associated effects on buildings and also the point that multi-level residential structures may experience higher vibration on the upper level are considered worthwhile in the context of providing future guidance for the types of town planning decisions made at a local government level that have enabled multilevel residential buildings to be developed directly adjacent to an operating quarry with regular blasting patterns.

I would also like to provide some clarification to your comment that it is considered your fault if your homes resonate. This relates to the required location of a monitoring device to determine compliance with blast vibration levels set for human comfort. Nobody is at fault for structural resonance. It does happen and internal vibration measurements leads to highly variable monitoring results as a result of structural resonance. Results obtained are highly influenced by the nature of the structure and the location of the placement of the monitor within it. EHP requires external monitoring as a means of ahieving a highly consistent measurement methodology and this is also predicated on the limits being set to protect human comfort.

I hope this advice is of assistance to you.

Regards,

Andrew Connor
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Environmental Services and Regulation
Department of Environment and Heritage Protection
P 07 3330 6335
Level 8, 400 George Street, Brisbane QLD 4000
GPO Box 2454, Brisbane QLD 4001

From: sch4p4(6) Personal Information
Sent: Sunday, 23 October 2016 10:17 AM
To: CONNOR Andrew; Mount.Coot-tha@parliament.qld.gov.au
Subject:

Re: Mt Coot-tha Residents Amendment Proposal to Standards Australia AS2187 Appendix J

Dear Steven and Andrew,

I have represent all the residents on quarry issues. Together over the past 20 years we have worked for hundreds of hours attempting to get the Mt Coot-tha blast vibration levels reduced and quarry operations improved.
After the recent letter from the Lord Mayor, we know that the reason our efforts are ignored is because of the outdated non-Australian vibration data in the Australian Standard AS2187 Appendix J.

Whilst the quarry tries to hide the total blast count, we believe the true count to be several thousand and the cumulative effect of this is a very serious concern of everybody here.
Appendix J has no concept of high blast counts, whilst the count here continues to increase every week. It also has no mention of damage to common electronic data storage equipment or historic buildings, all of which are well known to be vulnerable at the current blast levels. I believe that every home here has two or three hard drives and at Stuartholme school there would be hundreds.

The residents are also very concerned about how our buildings react to the current blast vibrations, it is considered to be our

rd

fault if our homes resonate from the vibration. (As you may know on the 3 August this year, the sound levels were professionally measured inside the new home of one of our resident's. This showed very alarming results with the noise persisting for more than 30 seconds after the blast.)

The quarry repeats their belief that the blasting levels are set for human comfort and could never damage a home.
We believe that this is totally invalid for many reasons, including those above. They refuse to consider any effects inside the homes.

ABC Radio National Scientist Dr Karl has published this news item regarding possible damage to hard drive data storage devices from sound vibrations, this audio energy level is considerably less than that caused by the quarry blasts.
http://www.abc.net.au/radionational/programs/greatmomentsinscience/loud-sounds-can-kill-computer-hard-drives/7938388

On behalf of all the Mt Coot-tha residents, we strongly ask that you support our efforts to have Appendix J amended.
If our homes resonate from the blast vibrations, this is not our fault.

Yours Sincerely, sch4p4(6) Perso

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From: KARLE Matt [Matt.Karle@des.qld.gov.au]
Sent: Thursday, 27 October 2016 10:31 AM
To: CONNOR Andrew; ROWE Sarah
Subject: AS 2187.2-2006
Attachments: 2187.2-2006.pdf

Hi Andrew

See attached pdf copy of AS2187.2 from Standards Online through EHP's online library subscription.

Specifically, Appendix J contains most info relevant to the AS2187.2 conversation, and specifically:

- J3.2.2 – Measuring technique (ground spikes etc)
- J3.3 Airblast
- J4 onwards- Ground Vibration Levels – specifically J4.4.2
- Table J4.4.2.1 – Transitent vibration for cosmetic damage
- Table J4.4.2.2
- Table J4.5(a) Vibration limits for human comfort chosen by some regulatory authorities
- Table J4.5(b) Recommended vibration for control of damage to structures
- Table J5.4(a) – airblast limits for human comfort.
- Table J4.5(b) – recommended airblast for damage control

A letter will be drafted to Australian Standards today and provided to you as a draft.

Regards

Matt Karle
Compliance Delivery Manager, South Queensland Compliance – Brisbane Moreton Bay
Environmental Services and Regulation
Department of Environment and Heritage Protection
P 07 5316 8403
33 King Street, Caboolture Qld 4510

Australian Standard™

Explosives—Storage and use

Part 2: Use of explosives

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PREFACE

This Standard was prepared by the Standards Australia Committee CE-005, Explosives, to supersede AS 2187.2—1993, *Explosives—Storage, transport and use*, Part 2: *Use of explosives*.

The objective of this Standard is to provide requirements, information, and guidance for the use of explosives, the management of a site where explosives are used and the destruction of excess or deteriorated explosives, which ensure risks are acceptable minimized. This Standard is for reference by manufacturers, suppliers, and users of explosives. In addition, it is for reference by regulators and beneficiaries of activities involving explosives.

The major changes in this revision include the following:

(a) Inclusion of requirements for large operations.

(b) Adoption of a risk management approach with a greater emphasis on planning.

(c) Use of the term ‘close proximity’ in lieu of specific distances.

(d) Where appropriate, removal of reference to approval by authorities.

(e) Inclusion of requirements for electronic and remote blasting.

(f) Significant changes to ground vibration and airblast overpressure assessment.

(g) Inclusion of a new appendix covering exclusion zones.

(h) Inclusion of requirements for the use of explosives in atmospheres greater than atmospheric pressure.

This Standard is one of a series which includes the following:

AS	
2187.0	Explosives—Storage, transport and use—Terminology
2187.1	Explosives—Storage, transport and use—Storage
2187.2	Explosives—Storage, transport and use—Use of explosives (this part)
2187.3	Explosives—Storage, transport and use—Pyrotechnics—Shopgoods fireworks—Design, performance and testing
2187.4	Explosives—Storage, transport and use—Pyrotechnics—Outdoor displays

The terms ‘normative’ and ‘informative’ have been used in this Standard to define the application of the appendix to which they apply. A ‘normative’ appendix is an integral part of a Standard, whereas an ‘informative’ appendix is only for information and guidance.

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FOREWORD

Explosives are a concentrated source of energy, and because of their chemical properties are capable of inflicting death or injury to persons or damage to property or the environment. Similarly, they present a security problem if someone has unlawful possession of explosives or if explosives are in the hands of the inexperienced or those with ill intent.

Explosives thus present a high risk with potentially severe consequences unless stored, transported and used by competent persons in a safe and secure manner.

This Standard provides information on hazards presented by explosives and ways to manage and control the identified risks at a level that is acceptable to the community and in accordance with safe and secure industrial practice.

It is highly recommended that persons required to handle and use explosives are familiar with AS/NZS 4360, *Risk management*. Similarly, it is recommended that management plans, used to facilitate safe work procedures, plans and processes dealing with explosives, be based on AS/NZS 4804, *Occupational health and safety management systems—General guidelines on principles, systems and supporting techniques*.

For the purpose of this Standard it is a fundamental requirement that persons are competent and authorized by their employer to handle and use explosives. Competence, with respect to handling and use of explosives, is recognized through compliance with relevant legislation and by having documentation confirming one or both of the following:

1 Current and valid shot firing ticket or licence applicable in the relevant State or Territory.

2 Currency with relevant competencies or qualification, attained through a national training package (i.e., endorsed under the national training system of the Department of Education, Science and Training).

Employers of persons who handle and use explosives also have responsibilities with regard to the safe and secure management of explosives by ensuring that systems are in place through legislation and their management plan (if required) to provide a safe place of work. From a security viewpoint, the presence and security of explosives on a worksite is the ultimate responsibility of the employer.

Frequent reference is made in this Standard to the risk management process, risk analysis and risk controls; it is fundamental that persons using or referencing this Standard have a basic understanding of these terms.

Some hazards or risk controls associated with the handling and use of explosives may not be referenced in this Standard. This is not a deliberate omission but the application of proper risk management techniques should be sufficient for such hazards to be identified for specific or unusual situations relevant to individual work sites.

STANDARDS AUSTRALIA

Australian Standard
Explosives—Storage and use

Part 2: Use of explosives

SECTION 1 SCOPE AND GENERAL

1.1 SCOPE

This Standard sets out the requirements and precautions for the use of factory-made commercially available explosives and certain explosives mixed or assembled at sites.

This Standard does not apply to the following:

(a) Safety ammunition.

(b) Propellant powders.

(c) Pyrotechnics, including fireworks, rockets, fog signals or the like.

(d) Purpose-designed and manufactured military explosives.

NOTE: This Standard should not be regarded as overriding statutory requirements, including licensing, but may be construed as a set of working rules to be used in conjunction with such requirements.

1.2 APPLICATION

This Standard shall be read in conjunction with AS 2187.0 and the definitions therein apply to this document except where a definition is given herein.

1.3 REFERENCED DOCUMENTS

Where a provision of any of the referenced documents (other than legislation) in this Standard is inconsistent with any provision of this Standard, the provisions of this Standard takes precedence.

The following documents are referred to in this Standard:

AS	
1019	Internal combustion engines—Spark emission control devices
1678	Emergency procedure guide—Transport
1678.5.1.002	Part 5.1.002: Ammonium nitrate
1742	Manual of uniform traffic control devices
1742.3	Part 3: Traffic control devices for works on roads
1743	Road signs—Specifications
2187	Explosives—Storage, transport and use
2187.0	Part 0: Terminology
2187.1	Part 1: Storage
2397	Safe use of lasers in the building and construction industry
2601	Demolition of structures

AS	
2670	Evaluation of human exposure to whole-body vibration
2670.2	Part 2: Continuous and shock-induced vibration in buildings (1 to 80 Hz)
2809	Road tank vehicles for dangerous goods (all parts)
4326	The storage and handling of oxidising agents
60529	Degrees of protection provided by enclosures (IP Code)
AS/NZS	
1768(Int)	Lightning protection
2211	Safety of laser products (all parts as applicable)
3000	Electrical installations (known as the Australian/New Zealand Wiring Rules)
3191	Electric flexible cords
4240	Remote controls for mining equipment
4360	Risk management
4804	Occupational health and safety management systems—General guidelines on principles, systems and supporting techniques
HB 76	Dangerous Goods—Initial emergency response guide
BS	
2050	Specifications for electrical resistance of conductive and antistatic products made from flexible polymeric material
6472	Guide to the evaluation of human exposure to vibration in buildings (1 Hz to 80 Hz)
7385	Evaluation and measurement for vibration in buildings
7385-1	Part 1: Guide for measurement of vibrations and evaluation of their effects on buildings
7385-2	Part 2: Guide to damage levels from groundborne vibration
ISO	
2631	Mechanical vibration and shock—Evaluation of human exposure to whole-body vibration
2631.2	Part 2: Vibration in buildings (1 Hz to 80 Hz)
USBM	
RI 8507	United States Bureau of Mines
Department of Transport and Regional Services	
ADGC	The Australian Code for the Transport of Dangerous Goods by Road and Rail
AE Code	Australian Code for the Transport of Explosives by Road and Rail

1.4 DEFINITIONS

For the purpose of this Standard, the definitions given in AS 2187.0 and those below apply.

1.4.1 Airblast

The sudden increase in air pressure, generated by a shock wave, produced when an explosive is detonated.

1.4.2 Airblast overpressure

See airblast.

1.4.3 Amplitude

Distribution of frequencies derived using Fourier techniques, often using a Fast Fourier Transform (FFT).

1.4.4 A-weighting

A frequency-dependent scaling of a sound wave that mimics the response of human hearing.

1.4.5 Bar down

See scale.

1.4.6 Blasthole

A hole that has been drilled or prepared for the purpose of being charged with explosives, or has been charged with explosives.

1.4.7 Branch line

A length of detonating cord or signal tube connected to a trunkline on one end and to which downlines are connected on the other end.

1.4.8 Close proximity

An acceptable distance determined through risk assessment procedures for a specific application unless the distance is legislated.

1.4.9 Competent person

A person who has acquired through training, qualification or experience, or a combination of these, the knowledge and skills to carry out the required task.

1.4.10 Component velocity

One of the orthogonal particle velocities; typically one of radial, transverse, or vertical velocity.

1.4.11 C-weighting

A frequency-dependent scaling of a sound wave often used for impulsive noise such as airblast.

1.4.12 Damage

Physical expression of threshold failure of structures, architectural elements and/or surrounding ground.

1.4.13 Deflagrating

An explosive burning process that occurs at a rate less than the sonic velocity of the explosive material.

1.4.14 Downline

A length of detonating cord, signal tube, safety fuse or wire, one end of which is connected to the primer in a blasthole. The other end may be connected to a trunkline, a branch line or an electrical circuit.

1.4.15 Electric detonator

A detonator that is initiated by the direct application of an electric current to a fuse head within the detonator via the detonator's lead wires.

1.4.16 Electronic detonator

A detonator where the delay timing is provided by electronic circuitry within the detonator and initiated by way of digital signals provided by specialized firing equipment. Prior to activating the electronic circuitry within, the detonator may be programmed by specialized computer or programming devices.

1.4.17 Fly

The undesirable projection of any material as a result of a blast

1.4.18 Flyrock

The undesirable projection of rock as a result of a blast.

1.4.19 Fourier transform

A transformation of a time history into its frequency spectrum.

NOTE: The reverse process is usually called an inverse Fourier transform.

1.4.20 Ground vibration

Mechanical energy (vibration) produced by a blast and transmitted through the ground.

1.4.21 Human comfort

Levels of ground vibration and/or airblast that do not cause discomfort to humans.

1.4.22 Lead-in line

The main line of signal tube that leads to the shot that usually exceeds 100 m in length. It can be initiated either by a signal tube starter, detonating cord or a detonator and terminated with a detonator.

1.4.23 On-site

At or near the intended place of use of explosives.

1.4.24 Overpressure

See airblast.

1.4.25 Particle velocity

The time history of the velocity of particles within the ground.

NOTE: Analogous quantities exist for acceleration and displacement, which are each related via appropriate integration or differentiation.

1.4.26 Peak component particle velocity

The peak level of the particle velocity for an individual component.

1.4.27 Powder factor

The mass of explosive required to blast a unit of material to produce a given outcome.

1.4.28 Primer

A cartridge or booster that either carries a detonator or is coupled to detonating cord, by which the remainder of a charge is detonated.

1.4.29 Remote firing

The act of initiating explosives using an exploder activated by means of remote-controlled signalling equipment.

1.4.30 Scale

The process of removing loosened material that is likely to endanger persons.

1.4.31 Shock wave

A propagating discontinuity (abrupt change) in stress/pressure and particle velocity.

1.4.32 Shotfirer

Person licensed or authorized to use explosives in the applicable jurisdiction.

1.4.33 Signal tube

A small bore, flexible plastic tube coated internally with an explosive powder so that it is capable of transmitting a shock wave along the length of the tube.

NOTE: The external surface of the signal tube is not normally affected by the transmission of the internal explosion, although side blow-outs may occasionally occur.

1.4.34 Signal tube starter

A device for initiating the explosion in a signal tube.

1.4.35 Source of ignition

A source of energy sufficient to initiate an explosive or ignite a flammable atmosphere, and includes naked flames, lighters, lit smoking materials (such as lit cigarettes), exposed incandescent material, electrical welding arcs, mechanical or static sparks, and electrical or mechanical equipment.

1.4.36 Sound level meter

A measuring device that measures the level of sound, and may provide dBL, dBA and dBC values.

1.4.37 Sound pressure level (dB)

A logarithmic scale of pressure with a reference pressure of 20 μPa.

1.4.38 Trunkline

The main line of detonating cord or signal tube on the surface of a blast (including underground blasts) to which branches or downlines are connected.

1.4.39 USBM

United States Bureau of Mines (now disbanded although publications are readily available).

1.4.40 Vector peak particle velocity (VPPV)

The peak level of the particle velocity calculated from the vector formed by the magnitude of the three orthogonal components of the particle velocity over their measured time history.

1.4.41 Zero-crossing frequency

The frequency calculated from the half-period associated with the zero crossings about an individual peak in a ground vibration or airblast time history.

1.5 REGULATORY AUTHORITIES

Explosives in each State and Territory are governed by appropriate regulatory authorities. Persons planning blasting operations should ensure compliance with the legislative requirements applicable to the activity to be undertaken.

The words ‘required’ or ‘approved’, where used in this Standard, refer directly to the appropriate regulatory authority or a competent person, whichever is applicable.

A permit may be required for people intending to purchase or use explosives.

The manufacture, purchase, sale, transport, storage or disposal of explosives are regulated in most circumstances in Australia by regulatory authorities in most States and Territories.

SECTION 2 GENERAL REQUIREMENTS

2.1 RISK

Users of explosives shall be constantly aware of the dangers associated with the use of explosives.

Whenever explosives are to be used, a competent person(s) should carry out a detailed risk assessment to identify all foreseeable potential hazards, and take appropriate steps to eliminate or reduce the likelihood and mitigate the severity of any effects of such hazards, so that risks are at an acceptable level.

NOTE: Some explosives may need approval for use in specific applications.

2.2 PLANNING

Before the commencement of any blasting operation, an investigation of the site or item to be blasted shall be carried out. On the basis of the investigation, in conjunction with considerations detailed in but not limited to Section 12, a blast management plan incorporating a risk assessment shall be prepared by a competent person. No blasting shall commence until the blast management plan has been authorized by a competent person. The blast management plan shall be in accordance with Appendix A.

Where conditions revealed during execution of the blasting operation necessitate changes in the blast management plan, notification shall be given and authorization confirmed before the proposed changes are commenced except in emergency situations.

Planning shall include, but not be limited to, the following:

(a) Risk assessment.

(b) A site safety management plan.

(c) Blast design.

The extent to which the above is undertaken shall be commensurate with the size, location, nature and complexity of the blasting operation to be undertaken.

2.3 EXECUTION

The blasting operation shall be executed by competent persons in accordance with safe working practices and the requirements of the blast management plan.

NOTE: Blasting and post-blast records should be maintained.

2.4 SOURCES OF IGNITION NEAR EXPLOSIVES

Operations that can lead to ignition or initiation of explosives shall not be carried out in close proximity to where explosives are being handled. In addition, sources of ignition, for example fire, spark and similar, shall not be brought within close proximity to where explosives are being handled, except such as may be necessary to handle, charge or initiate an explosive.

2.5 BLAST EQUIPMENT

For the purposes of this Clause, the term ‘blast equipment’ includes equipment used for the initiation of detonators by the use of signal tube, electrical, electronic or remote systems.

Blast equipment shall be in a sound condition and suitable for the blasting operation being undertaken. Faulty or poorly maintained blast equipment shall not be used. The shotfirer shall ensure that the blast equipment is fit for its intended purpose and safe to operate.

Equipment used for testing and firing electric detonators shall comply with, and, where appropriate, be tested in accordance with Appendix B.

Equipment used for testing and firing electronic detonators, remote initiation and non-electric initiation shall be tested, calibrated and maintained in accordance with manufacturer's recommendations.

2.6 REPORTING OF THEFT OR LOSS OF EXPLOSIVES

Identification of loss or theft of explosives can be either manifest discrepancy or physical evidence of theft. Where a discrepancy, theft, or attempted theft, of explosives has been verified, it shall be immediately reported to the appropriate authorities.

2.7 REPORTING OF DAMAGE OR INJURY

2.7.1 Damage to property

Where property is inadvertently damaged by blasting operations, there may be a requirement to report such damage to the appropriate authority.

2.7.2 Injury or death to person(s)

Where injury or death to a person(s) occurs as a result of blasting operations, the incident shall be reported to the appropriate authority or authorities. Care shall be taken to not unnecessarily disturb, move or remove any equipment or material other than to rescue or protect any injured person until permission has been granted by the appropriate authorities.

2.7.3 Damage to the environment

Where the environment is inadvertently damaged by blasting operations, there may be a requirement to report such damage to the appropriate authority.

2.8 EMERGENCY PROCEDURES

Emergency procedures should be developed for any site where explosives are used, stored or manufactured. These procedures may be developed as part of the site safety management plan dealing with risk.

Possible emergency situations include but are not limited to the following:

(a) Fire.

(b) Transport accident.

(c) Natural phenomena.

(d) Unplanned detonation.

(e) Unauthorized site entry.

(f) Deteriorated explosives.

SECTION 3 ON-SITE MANUFACTURE OF EXPLOSIVES

3.1 GENERAL

Explosives may be manufactured on-site in readiness for blasting. Where this is done a detailed risk assessment of the operation shall be carried out and appropriate operating procedures developed to ensure all identified hazards have been reduced to an acceptable level.

This Section provides requirements for the manufacture of ANFO and for mobile mixing units.

Most jurisdictions require that preparation areas, raw material storage areas and mixing equipment be duly licensed. States and Territories of the Commonwealth may have legislation that applies to site manufacture of explosives.

3.2 MATERIALS

The materials used in the mixing of explosives on site shall be either in accordance with Clause 3.5.2 for ANFO or as specified by the manufacturer for other explosives. Variations shall not be made to either the constituent materials or the method of mixing.

Ingredients used in the mixing of explosives shall be stored and transported such as to prevent accidental mixing.

Ingredients shall be clean and free of all foreign materials.

A comprehensive waste disposal plan for the collection and disposal of waste ingredients and waste packaging materials shall be in place. This shall take into account the possibility of all waste being contaminated with explosives.

3.3 FIRE PRECAUTIONS ON MIXING SITES

The following precautions shall be taken to minimize the possibility of fire at any place where explosives are mixed:

(a) Surroundings within close proximity shall be kept clean and free from all combustible material.

(b) Smoking shall not be permitted within close proximity.

(c) Operations constituting a fire hazard, such as welding, grinding, cutting or the like, shall not be conducted on or within close proximity of a mixing plant unless all mixed explosive has been isolated from the source of possible ignition.

(d) A detailed evacuation plan shall be developed to quickly and safely evacuate people from the site and immediate surrounds to a safe place in case a fire gets out of control. The safe place shall be as set out in the risk management plan.

NOTES:

1 In large mixing houses, not of a temporary nature, a water flooding system with external valves is recommended so that all equipment and adjacent areas may be flooded at the first sign of fire. An appropriate open drainage system directed to an area where the propagation of fire can be contained is also recommended.

2 Because of the possibility of explosion, if a fire that cannot be controlled occurs, the area should be evacuated in accordance with established procedures.

3 Appendix C gives guidance on fire precautions.

The treatment of fires should be a component of the blast management plan.

3.4 MIXING APPLIANCES AND BUILDINGS

3.4.1 Appliances

Appliances and associated equipment used for mixing explosives shall comply with the following:

(a) Materials used in the construction of such equipment shall be compatible with all the ingredients, particularly ammonium nitrate. Where contact with ammonium nitrate cannot be avoided, galvanized steels, zinc, copper and alloys of these metals shall not be used (see Note 1).

(b) Machines used for mixing shall—

  (i) be designed to minimize the possibility of frictional heating, compaction, overloading, accumulation of compositions and confinement;

  (ii) have bearings, motors or gears protected from spillages of material (see Note 2); and

  (iii) be designed to facilitate cleaning operations.

(c) All systems used for the measuring of ingredients shall be calibrated in accordance with manufacturers' recommendations.

(d) The frames of all mixers and any associated equipment shall be effectively bonded and a continuous electrical path to earth provided.

(e) Spark ignition (petrol-fuelled) engines shall not be used for power-operated mixers.

(f) In the construction of mixing appliances, the potential for build-up of explosive mixtures shall be avoided (see Note 3).

NOTES:

1 Certain materials form sensitive compounds with ammonium nitrate, which may be hazardous. For this reason, their use is prohibited for mixing vessels, internal linings or where the material is likely to come into contact with ammonium nitrate, ANFO or similar mixtures. This also precludes their use as corrosion-resistant treatments for internal fastening devices for linings such as nails or screws. Steel, stainless steel, aluminium and some anti-static plastics materials are generally suitable.

2 Bearings that have cotton or similar materials used as packing should not be used.

3 Solid sections (e.g., rods, angles, channels and T-sections) are preferred. Hollow sections, especially those that are sealed, represent a particular hazard should explosive mixtures work their way behind faulty welds or into worn parts. If hollow sections are used, they should be left open and/or provision made for cleaning.

4 Plain steel nails and screws may be used but they suffer from the serious disadvantage of accelerated corrosion in the presence of ammonium nitrate.

3.4.2 Mobile mixing units

In addition to the general requirements set out in Clause 3.4.1, mobile mixing units shall comply with the following where applicable:

NOTE: Requirements for the transport of dangerous goods are set out in the Australian Code for the Transport of Dangerous Goods by Road and Rail (ADGC).

(a) The vehicle shall be roadworthy and in sound mechanical condition and repair.

(b) The body of the vehicle shall be constructed of materials that are not combustible.

(c) The engine and exhaust system shall be located forward of the rear of the cabin or shielded in accordance with the AS 2809 series. A compression engine shall be fitted with an exhaust spark arrestor in accordance with AS 1019.

(d) Any battery shall—

  (i) be secured to prevent movement in the event of vehicle overturn;

  (ii) be in an accessible position; and

  (iii) have a substantial acid-resistant and ventilated cover that is electrically insulated on the side adjacent to the battery terminals.

(e) A battery isolation switch shall be fitted and arranged to isolate the battery from all circuits and equipment, except where the maintenance of electrical supply to certain vehicle instrumentation within the cabin is acceptable to the regulatory authority.

The means of operating the isolation switch shall be—

  (i) located on the right-hand side of the vehicle immediately to the rear of the cabin, in such a position that it is clearly visible and easily accessible to a person outside the vehicle, yet protected against any detrimental effects of sunlight; and

  (ii) clearly labelled to indicate its function and method of use.

(f) Where the engine is fitted with an alternator, the battery isolation switch shall be of a type that automatically opens the alternator field coil circuit immediately before the battery is isolated.

(g) Electrical cables shall comply with AS 2809 series, be of stranded copper with a minimum of 7 strands and of adequate current-carrying capacity and, except on battery and starter cables, be provided with terminals of the insulation gripping type.

(h) Wiring outside and to the rear of the cabin shall be carried in conduit in accordance with AS 2809 series, or as otherwise approved by the regulatory authority.

(i) Each circuit, except the starting and ignition circuit, shall be protected by a fuse or manual-reset circuit-breaker in accordance with the following requirements:

  (i) The current rating of the fuse or circuit-breaker shall not exceed the rated current-carrying capacity of the conductor.

  (ii) Circuit-breakers shall be of the manual-reset type with instantaneous short-circuit protection capable of repeatedly opening the circuit in which it is used, without failure.

(j) Where the mixing appliance is to be used to load free-flowing granular explosives pneumatically, consideration shall be given to the provision of an adequate earth (see Clause 6.2).

(k) Where the vehicle fuel tank is located to the rear of the cabin, it shall be—

  (i) protected so that the likelihood of accidental damage is minimal; and

  (ii) designed to prevent accumulation of spilt fuel on any part of the vehicle.

(l) A quick-acting fuel cut-off device shall be fitted to the engine fuel supply line. It shall be fitted in such a position that it is effective, clearly visible and easily accessible to a person outside the vehicle, and clearly labelled to indicate its function and method of use.

(m) The design of the processing equipment shall also provide for the effective segregation of ingredients prior to mixing (including minimizing the possibility of mixing during incident/accident conditions).

(n) All ingredients and explosives shall be adequately protected against direct sunlight and adverse weather conditions. Such protection shall be secure and not liable to be dislodged during normal transport.

(o) When electric power is supplied to any processing equipment by a self-contained motor-generator located on the vehicle, the motor-generator shall be separated from the explosive discharge area of the vehicle.

(p) Pressure relief shall be provided on containers of ingredients or explosives that might produce pressures under confinement or in the event of fire. The pressure relief shall be installed in such a manner that protection is provided against permanent closure in an accident. If a pressure-relief valve is fitted as the pressure relief mechanism, then it shall be directed so as to prevent harm to personnel in the vicinity of the vehicle.

NOTE: Pressure relief may be provided by means other than pressure-relief valves.

(q) Tanks for liquid ingredients or explosives shall be constructed to dampen movements of the contents during transport if such movements are liable to cause a loss of vehicle control or any other hazardous situation.

(r) All tanks and storage equipment shall comply with AS 4326.

(s) All processing equipment shall be firmly and effectively secured to the body of the vehicle. All mobile equipment, including hoses, shall be effectively restrained while travelling.

(t) All transfer equipment, including delivery hoses, shall be adequately restrained to ensure control is maintained during transfer operations.

(u) A positive action parking brake, which will set the wheel brakes on at least one axle, shall be provided on vehicles equipped with air brakes and shall be used during delivery operations. Wheel chocks shall be provided on the vehicle to supplement parking brakes whenever required.

(v) The mixing and delivery system shall be arranged so that the operator in normal position during operations has full view of explosives delivery points, or has adequate communication with another operator who does have such a view.

(w) The mixing and delivery systems shall be equipped with an emergency stop, appropriately labelled and in easy reach of the operator monitoring these operations.

(x) All processing equipment including tanks, hoses, taps and valves shall be clearly labelled to properly identify contents and use.

(y) The vehicle shall be marked as follows:

  (i) When carrying explosives, the vehicle shall be marked in accordance with the AE Code

  (ii) When carrying only ingredients of explosives, markings for any dangerous goods carried in sufficient quantities shall be as required by the Australian Code for the Transport of Dangerous Goods by Road and Rail.

  (iii) Where 'EXPLOSIVES' signs are not required for mixing vehicles, such signs shall be available for display at the site during mixing operations.

  (iv) The following signs warning about moving augers and the need for eye protection shall be displayed:

    (A) 'EYE PROTECTION MUST BE WORN WHEN IN OPERATION.'

    (B) 'CAUTION—AUGERS MAY MOVE WITHOUT WARNING.'

(z) The vehicle shall be equipped with emergency procedure guides appropriate to the materials being transported.

NOTE: For further guidance see AS 1678.5.1.002 or HB 76 as applicable.

3.4.3 On-site mixing-house buildings

On-site mixing-house buildings shall comply with the following:

(a) They shall be constructed so as to minimize the risk of fire.

(b) They shall have non-oil-absorbent floors with an adequate open drainage system to the outside.

(c) Materials in excess of current mixing requirements shall not be stored in the buildings. Raw material used in the process should be stored in accordance with AS 2187.1 or the relevant Australian Standard appropriate to the raw material.

(d) All electrical installations including circuits and switching shall comply with the relevant requirements of AS/NZS 3000. All electrical equipment enclosures shall comply with a rating of IP55 in accordance with AS 60529.

NOTE: Particular attention should be paid to the possible existence of combustible dusts, such as powdered aluminium in mixing operations, which may necessitate a higher degree of protection for electrical equipment. In such cases the regulatory authority should be consulted.

(e) When explosives are prepared at a central mixing plant or in several mixing-house buildings, such buildings shall be located in accordance with the safety distances specified in AS 2187.1.

(f) Lightning protection shall be installed in accordance with AS/NZS 1768(Int).

(g) Attention shall be given to the possible accumulation of gases or fumes or oxygen deficiency.

3.5 MANUFACTURE OF ANFO

3.5.1 General

ANFO (Ammonium Nitrate Fuel Oil) is an explosive that is often mixed on-site or close to the point of use. It is relatively simple to manufacture. Mixing and handling of ANFO shall be with done with extreme care. ANFO is ideal for use in dry blastholes but its performance can be readily affected by moisture or wet conditions. Ammonium nitrate is very soluble in water.

3.5.2 Materials

3.5.2.1 *Ammonium nitrate*

Only porous prilled ammonium nitrate shall be used in the manufacture of ANFO. Other forms of ammonium nitrate should not be used as misfires can result.

3.5.2.2 *Fuel oil*

Fuel oil, or other oil used for mixing with ammonium nitrate, shall be clean, with a closed-cup flashpoint of 60.5°C or higher. The oil shall be of such a viscosity that it is readily absorbed by the ammonium nitrate.

NOTE: Automotive diesel fuel (distillate) is recommended for standard ANFO.

3.5.2.3 *Additional materials*

The addition of other materials, such as polystyrene or aluminium powder, when used, shall be in accordance with the manufacturer's specifications. Such additions may require regulatory approval.

3.5.2.4 *Colouring agent*

A colouring agent, which is soluble in the fuel oil, should be used as a guide to ensure that the fuel oil is uniformly and thoroughly blended with the ammonium nitrate. The use of a colouring agent will also enable mixed explosive product to be readily differentiated from the unmixed ingredients.

3.5.3 Mixing of ANFO

The ammonium nitrate and fuel oil shall be thoroughly blended to create a uniform mix.

Fuel oil used to manufacture ANFO shall be nominally 6% by mass of ammonium nitrate. The quantity of fuel oil is critical. Excess oil leads to a slight reduction in blasting effect and a moderate increase in the volume of toxic fumes released; and insufficient oil leads to a considerable reduction in blasting effect and a moderate increase in the volume of toxic fumes released.

Table 3.5.3 gives the correct proportions to be used for quantities of ammonium nitrate up to 50 kg, within the 6% limit.

TABLE 3.5.3

QUANTITIES OF MATERIALS FOR SMALL BATCHES OF ANFO

Ammonium nitrate (Kg)	Fuel oil (5.8%) (L)
10	0.75
20	1.5
25	1.90
30	2.25
40	3.00
50	3.75

3.6 STORAGE OF ON-SITE MANUFACTURED EXPLOSIVES

Where large-scale mixing operations necessitate an extended delivery time, storage between mixing plant and the point of usage is acceptable, provided that such stored explosives are in a receptacle suitable and safe for its intended purpose and placed in a magazine.

NOTES:

1 Explosives should be mixed as required and in quantities sufficient only for current use.

2 Prolonged storage of ANFO can result in oil migration or absorption of water, with a resultant loss of sensitivity in the explosive, which can result in misfires.

3 Oil migration or absorption of ammonium nitrate can create a fire hazard in timber-lined magazines.

SECTION 4 PLANNING

4.1 GENERAL PROVISIONS

All blasts, whether surface, underground or submarine, shall be planned and designed to achieve the required outcome with first considerations being the protection of persons, property and the environment.

Before the commencement of any blasting operation an investigation of the site and its environs, or the item to be blasted, shall be carried out identifying any potential hazards/risks. On the basis of the investigation, a blast management plan incorporating a risk assessment and control measures shall be prepared.

4.2 BLAST MANAGEMENT PLAN

There shall be an overall blast management plan in accordance with Appendix A. Records should be maintained. No blasting shall commence until a competent person has authorized the blast management plan.

4.3 ADMINISTRATION AND LEGISLATION

People planning blasting activities have an obligation to identify and assess the relevant licences, permits or legislative requirements needed for blasting activities. These may include the following:

(a) Appropriate shotfirer's licence and qualifications for blasting activity.

(b) Permits to purchase explosives.

(c) Permits to receive explosives.

(d) Licences to manufacture explosives.

(e) Explosives storage licences and requirements.

(f) Explosive transport licences and requirements.

(g) Type of explosives, authorizations and availability.

(h) Dangerous goods storage and transport requirements.

(i) Requirements set out by other government departments/authorities.

Planners shall identify and assess reporting requirements and controls that are necessary to minimize the undesirable effects of blasting (e.g., loading procedures, monitoring procedures, drilling procedures, load charts, timing plants, maintenance records, etc).

Planners shall ensure that a blast management plan is completed prior to any blasting activity, and maintained in accordance with any legislative requirement.

4.4 SAFETY AND SECURITY

Safety and security are priority goals of the risk management process for the blast management plan. Areas for consideration in the risk management process include but are not limited to the following;

(a) Influence of the surrounding environment.

(b) Blast methodology, for example, selection of explosives, means of initiation and related equipment required, onsite manufacture.

(c) Transport to and from site (see the AE Code).

(d) On-site transportation.

(e) Storage of explosives (on-site or off-site).

NOTE: The type of blasting operation may influence the selection of a preferred location and means of storage.

(f) Stock reconciliation.

(g) Operational security, e.g., sentry locations and traffic flow.

(h) Prevention of unauthorized access.

(i) Traffic flow at the blast location.

Other aspects may be highlighted during the risk assessment process.

4.5 BLASTING HISTORY AND CONSULTATION

Consultation with any parties that have been involved in similar operations may provide valuable information to assist in identifying hazards/risks that may have been present. Where accessible, any previous records of blasting in similar conditions or applications shall be reviewed. Any safety information or site procedures in accordance with the blast management plan, which may already be in place, shall be identified and assessed.

4.6 PHYSICAL CHARACTERISTICS AND GEOLOGY

The physical characteristics and potential hazards, which may be associated with the characteristics of the material to be blasted, shall be identified and assessed. The purpose of the assessment is to determine any inconsistencies in relation to the material being blasted, which may prevent an effective blast from being carried out. This information can come from exploration samples, drill operators, geological surveys and reports, and blasting history related to the site. Factors for consideration include but are not limited to the following:

(a) Geological structure, e.g., faults. fissures, instrusions.

(b) Varying rock type.

(c) Oxidizing/reactive ground.

(d) Hot/high temperature material.

(e) Consistency of material, e.g., voids, layering, floaters.

(f) Flammability or combustibility of material.

(g) Presence of hazardous atmospheres.

(h) Presence of water, e.g., tidal, flow, depth.

(i) Blasting in atmospheres greater than atmospheric pressure.

(j) Brittleness of material.

(k) Previous mine workings.

(l) Characteristics of the face.

4.7 RESPONSIBILITIES

The blast management plan shall comprehensively document the allocation of responsibilities.

The person with overall responsibility encompassing each and every stage of the blasting operation shall ensure that the people assigned specific duties are competent for the tasks assigned. The person assigned responsibility for the blasting operation shall confirm that persons assigned specific duties understand the requirements or activities to be performed. This includes public and site notification, special vehicle requirements, signage, provision of competent persons, and any other equipment/procedures identified in the blast management plan.

The plan shall have provisions for the handing over of responsibilities where shiftwork is in progress and explosives-related activities are incomplete.

Specific responsibilities may also be assigned in regulations.

4.8 ENVIRONMENTAL IMPACTS

The area surrounding the blast site should be inspected and assessed to determine appropriate means of minimizing environmental impacts. Regulatory limits may apply.

In conducting the risk management, foreseeable factors should be considered, including, but not limited to the following:

(a) Distances to buildings, structures, and other environmental effects.

NOTE: See Appendix J for guidance.

(b) Identification of monitoring requirements and the requirement for monitoring locations, systems and instruments.

(c) Ground vibration and airblast overpressure.

NOTE: See Appendix J for information and guidance on the environmental effects of ground vibration and airblast overpressure.

(d) Effects of various weather patterns and wind directions.

(e) Effects of dust, fume, sediment run-off, noise.

Any of the above factors can be expected to have an impact on the blast design. It should also be noted that significant lead times may apply to any required interruption to utilities, e.g., gas, water, electricity.

4.9 GENERAL SAFETY PRECAUTIONS

4.9.1 Working at or below heights

The blasting process often involves working at or below heights where fall hazards exist. Standards and site rules should be complied with.

4.9.2 Services

Due to the equipment used and activities undertaken during blasting, services can pose a significant hazard. Services that may be affected by the blast or that might themselves affect the blast shall be identified. Such services may include, but are not limited to the following:

(a) Energy systems, e.g., electricity.

(b) Water.

(c) Gas.

(d) Communication cables.

(e) Effluent systems.

(f) Steam.

These services could be located above, at or below the surface.

4.9.3 Environmental hazards

All persons performing outdoors activities, including manufacturers of explosives in on-site mixing-house buildings, have potential exposure to environmental hazards. These hazards can include the following:

(a) Lightning.

(b) Wind.

(c) Rain.

(d) Hail.

(e) Snow.

(f) Flooding.

(g) Cyclones.

(h) Fire.

(i) Dust storms.

If the manufacturing, mixing or blasting operation is likely to be exposed to any of the above, then an appropriate risk control or procedure shall be actioned. The risk assessment should form part of the emergency response planning process.

4.10 SPECIAL PRECAUTIONS

Due to the many environments in which blasting takes place, not all hazards can be identified and raised in this document.

The onus is on the entities undertaking blasting activities to use this document, and specialist experience within the blasting operation they are undertaking, to manage risks associated with the blasting activity. It is foreseeable that every blasting operation will have specific and special precautions that need to be implemented for the safety and health of persons, property and environment.

4.11 BLAST DESIGN

After performing the risk assessment process, the blast design should be formalized. A document control process should be established to ensure that all persons involved in the blasting operation have access to all necessary documentation, including the correct blast design for the task. In some jurisdictions, the blast design may be required to be submitted to a regulatory authority for approval, e.g., demolition.

The blast management plan shall outline the objective of the blast. The objectives may include the following:

(a) Fragmentation.

(b) Movement.

(c) Environmental considerations.

(d) Preservation of the stability of adjacent rock.

(e) Minimization of back-break/over-break.

These objectives may be applied to the following operations:

(i) Open cut blasting.

(ii) Underground blasting.

(iii) Submarine blasting.

(iv) Construction/demolition/agricultural blasting.

(v) Secondary blasting.

(vi) Blasting in confined spaces.

Parameters required for the blast shall be identified and assessed by applying basic shotfiring calculations. The explosive requirements shall be identified by determining or calculating the following:

(A) Powder factor.

(B) Burden.

(C) Spacing.

(D) Hole diameter.

(E) Subdrill.

(F) Stemming.

(G) Initiation system and delay sequence.

(H) Type of explosive required (e.g., ANFO, wet hole products, presplit products, and similar).

(I) Explosive loading/detonation sequence/effective charge mass per delay (MIC).

(J) Calculation of predicted ground vibrations.

Where conditions revealed during execution of the blasting operation necessitate changes in the blast plan, notification shall be given to the competent person who approved the initial plan and authorization re-confirmed before the proposed changes are commenced, except in emergency situations.

SECTION 5 BLAST PREPARATION

5.1 BLAST MANAGEMENT PLAN

The person with responsibility for the blast management plan should ensure that blast preparation can commence in accordance with the blast management plan.

Prior to the blast preparation process proceeding, the site shall be inspected and the blast plan shall be reviewed to ensure that it is still valid and any significant variations are identified and assessed.

5.2 BLAST AREA PREPARATION AND ACCESS

5.2.1 General

The blast area and access shall be prepared so that it is safe and suitable for its intended purpose. For example, the area shall be large enough for plant to manoeuvre safely and effectively in a way to avoid damaging blastholes already drilled.

5.2.2 Access

Provision should be made for the intended access to and from the blast area to be in suitable condition under the predominate weather conditions that would be expected during blasting operations.

The area around the blast site should be properly delineated in accordance with Appendix L.

5.2.3 Pattern markout

Good blasting results require the following:

(a) Accurate and clear drilling plans.

(b) Accurate marking of the positions of intended blastholes.

Intended blastholes should be located safely e.g., located parallel or away from a butt, located for the safety of drilling operations. The use of toe holes may need to be considered.

5.2.4 Hole diameter

Blastholes shall be of sufficient diameter as to permit free insertion of the charge without ramming, forcing or removal of cartridge wrapping.

5.2.5 Pre-drilling examination

Before drilling commences, the area in close proximity to the intended blasthole shall be examined for the presence of explosives. If examination reveals explosives are present, they shall be treated as misfires in accordance with Section 10.

5.2.6 Drilling

The drilling process is extremely important to the outcome of most blasting activities, it is the foundation for a successful blast. In order to achieve successful blasting outcomes it is important that blastholes are drilled according to an accurate plan. To ensure this occurs, the following applies:

(a) A clear communication system between shotfirers and drillers shall be implemented and used.

(b) The driller shall record and report any unusual events during the drilling, e.g., cavities, soft rock, an inability to drill holes in accordance with the blast plan.

(c) Verification of the blasthole length and orientation should be carried out and compared with the blast plan. Where deviations are found, they shall be identified, recorded, assessed and remedial action shall be taken where required.

5.2.7 Drilling in cut-offs or butts

Drilling shall not be carried out in cut-offs or butts, except where it is carried out using remote-controlled drilling equipment, or other procedures that offer equal or greater safety to operators.

5.2.8 Prevention of blasthole blockage

Measures should be implemented to prevent the unintentional entry of drill cuttings, surface debris and spoil/stemming material into blastholes via the collar.

SECTION 6 OPERATIONS PRIOR TO CHARGING

6.1 BLAST AREA MANAGEMENT

6.1.1 Blast management plan

The person with responsibility for the blast management plan should ensure that charging can commence in accordance with the blast management plan.

6.1.2 Charging material availability

All materials required for the completion of the shot loading and firing should be available to ensure the safe completion of the charging operation. These materials may include, but are not limited to, the following:

(a) Bunting and signage.

(b) Stemming.

(c) Explosive products.

(d) Gas bags.

(e) Tamping sticks.

(f) Testers.

(g) Tape measure.

The person with overall responsibility for the blasting operation should ensure that all items required for the blast are identified and available in a timely manner. This is especially important for the delivery of explosive products due to the need for specialized transport.

6.1.3 Blast area inspection

A blast area inspection shall be conducted before loading commences. Any hazards identified as posing an unacceptable risk shall be mitigated.

6.1.4 Environmental conditions

An assessment of environmental, including weather, conditions should be made prior to any loading activities. If conditions that would cause the stoppage of loading are expected or predicted during the charging period, a review of the required charging should be undertaken in accordance with the blast management plan. This is especially important for operations where circumstances require charging and firing to be completed in a limited time period.

6.1.5 Precautions at site

The operation shall establish, within the blasting plan, a non-work-zone around the blast area. The non-work-zone should be established taking into consideration vehicle movements adjacent to the blast area, plant maintenance and other non-blasting-related activities.

Where charging operations are occurring at more than one location at a particular site, adequate communication shall be maintained between each operation if there is a likelihood of one or more of the locations affecting another.

There shall be no sources of ignition introduced into the blast area other than that which is required to initiate the shot. This shall not preclude the plant required for charging operations. Plant to be used in the blast area shall be assessed for its suitability and unacceptable risks shall be mitigated before it is used.

6.1.6 Traffic management

The movement of vehicles in and around a blast area can pose a significant risk. It is critical that all potential vehicle interactions with initiation systems are identified and managed. For example, where signal tube initiation systems are used, entanglement may occur with a moving vehicle and this is the main mechanism by which ‘snap, slap and shoot’ incidents occur, which can cause unintended initiation.

The impact of vehicular traffic on the area should be subject to risk assessment and control measures should be developed. Issues that should be included in the risk assessment are the following:

(a) Access to and around the blast area.

(b) The interaction of vehicles with other vehicles and personnel.

(c) The blasthole layout and the ability to reach each blasthole without driving over blastholes or explosive products.

(d) Control of activities on or immediately adjacent to a blast site.

As a result of this process, the following outcomes should be attained:

(i) Traffic management is incorporated in the blast management plan.

(ii) Difficult to reach blastholes are identified and subsequent loading plans are prepared, e.g., load difficult to reach blastholes first.

(iii) The maximum number of vehicles allowed in the blast area at any one time is declared in the blast plan and controlled on site.

(iv) Procedures for the management of vehicles caught in difficult situations should be prepared.

6.1.7 Blasthole measuring

The blastholes shall be checked prior to loading for location, depth, diameter, angle and presence of water.

A system of blasthole identification should be developed. Such a system should aid in the clear communication of loading requirements, especially for blastholes requiring special treatment. Examples of issues that require identification include the following:

(a) Blastholes that contain water.

(b) Blastholes that are to be decked.

(c) The initiation blasthole.

(d) Blastholes that have partially or fully collapsed.

(e) Blastholes that vary from the blast plan.

When variances from the blast management plan are discovered, their effects should be assessed and any unacceptable risks should be mitigated.

6.1.8 Loading sequence

The sequence of loading should ensure safe and efficient blast charging and take into account vehicle movements. Loading should be undertaken in a sequence that enables a portion of the blast to be sectioned off, tied and initiated, if an unexpected event occurs before all loading is completed, e.g., thunderstorm approaches.

6.1.9 Sleeping

Where charged blastholes are left unfired, adequate safety and security measures shall be developed and implemented to protect people and property.

The blast management plan should include procedures for sleeping charged blastholes, and considerations include, but are not limited to, the following:

(a) The explosive manufacturer's recommendations.

(b) Temperature of the ground.

(c) Groundwater.

(d) Steps to be taken to secure the area from unauthorized entry.

6.1.10 Night loading or poor visibility

Where blastholes are being loaded when natural sunlight is not adequate to light the blast area, additional hazards arise, which shall be identified and addressed. Such hazards include but are not limited to the following:

(a) Artificial light glare.

(b) Shadow formation.

(c) Visibility of blasthole locations and personnel working on the blast (i.e., the ability to see and be seen).

(d) Fatigue.

(e) Identification of correct charging materials.

(f) Taking and recording correct charging measurements.

6.2 PNEUMATIC CHARGING

Where pneumatic charging devices are used, they shall be effectively electrically earthed, and semi-conductive (antistatic) loading tubes shall be used. Such tubing shall have a resistance of not less than 15×10^3 Ω/m and shall be of such length that its resistance is not more than 2 MΩ. The resistance shall be measured as described in BS 2050.

The charging devices and associated equipment shall be earthed to give a total resistance to earth of not more than 1 MΩ. Water lines, compressed air lines, wire-covered hoses, rail or permanent electrical earthing systems shall not be used as a means of earthing.

NOTE: The possibility that pneumatic charging devices may generate static electricity, which may accumulate in sufficient amounts to cause premature detonation of the priming charge, have to be recognized. Before pneumatic charging is employed in any operation, thorough tests, using appropriate equipment, should be made to evaluate this hazard. Pneumatic devices should not be used in full-scale operation until such tests are completed and evaluated (including the introduction of additional safety factors to account for all variations in rock conductivity, sensitivity, temperature, humidity and air pressure that might occur).

6.3 PREPARATION OF CHARGES

6.3.1 Capping safety fuse

6.3.1.1 *Capping site*

The fitting of fuses to detonators shall not be carried out within close proximity of a magazine or other place where explosives are stored, and then only in an area protected from weather and dust.

Capped fuses not required for immediate use shall be placed in a suitable receptacle or stored in a detonator magazine.

6.3.1.2 *Safety fuse*

Safety fuse used shall comply with the following requirements:

(a) It shall be inspected for damage and tested for burning rate, both on receipt and prior to use, to ensure that its condition has not been adversely affected by storage.

(b) If damaged in any way, it shall not be used.

(c) If being used in damp conditions, the first and last 300 mm of exposed fuse shall be discarded if left for periods in excess of 1 h.

(d) The burning rate of safety fuse, when determined on 1 m long samples, shall be such that a sample shall burn in not less than 90 s and not more than 120 s when tested at sea level.

(e) The minimum length of fuse for all charges shall be 1 m. In any event the length shall be such that the person firing the charge has sufficient time to withdraw from the blasting area to a safe location without undue haste.

(f) The end of the fuse for insertion in the detonator shall be cut square, and only an end that is dry, clean and freshly cut shall be inserted into any detonator.

NOTE: The end of the fuse intended for lighting should also be freshly cut.

6.3.1.3 *Inspection of plain detonators*

Before insertion of the fuse, detonators shall be examined to ensure they are not physically damaged, deteriorated or otherwise corroded and are free from condensation or foreign matter.

WARNING: DO NOT CLEAN DETONATORS BY BLOWING OR PRICKING WITH ANY TOOL OR IMPLEMENT.

6.3.1.4 *Insertion of fuse in detonators*

A fuse shall be inserted into a detonator by being pushed gently, without twisting, into contact with the detonator composition. The detonator shall be crimped to the fuse, 3 to 5 mm from the open rim of the detonator, by means of a purpose-made crimper.

NOTE: The detonator should be held in such a manner as to reduce the possibility of personal injury in the event of accidental detonation, i.e., pointing away from the body.

WARNING: A CAPPED FUSE CAN BE INITIATED BY STATIC ELECRICITY.

6.3.1.5 *Waterproofing of detonator and fuse junction*

Where a fuse is used in a blasthole or any situation containing free water, the crimp at the junction of the fuse and detonator shall be made waterproof.

NOTE: If necessary, waterproofing compounds that are not reactive with explosives or the safety fuse may be used.

6.3.2 Testing electric detonators

Where electric detonators are tested for electrical resistance before use, such tests shall be performed using a circuit tester as specified in Appendix B and the detonator under test shall be so shielded that no injury can result to persons in the vicinity. Such tests shall be conducted in a manner that precludes the possibility of detonation of other explosives should the detonator itself explode. The detonator shall not be used if the electric resistance is not within the range given in the manufacturer's specification.

NOTES:

1 The electrical resistance of each electric detonator should be tested individually before use.

2 The time that a detonator is kept in a shield should be at least twice the delay time of the detonator.

3 Steel pipe used as a shield should not be less than 50 mm diameter as it may fragment when in contact with an exploding detonator. A 50 mm diameter steel tube (minimum wall thickness 3 mm) or a bucket of dry sand into which the detonator is fully inserted would normally be suitable.

6.3.3 Preparation of primers

Primers should be made up immediately prior to charging.

The initiating medium used to form a primer shall have sufficient strength and sufficient contact with the primer cartridge (or in the case of cast primers their design for use will be such) to ensure initiation and shall be attached in such a way that it will not become detached from the primer cartridge during loading.

Where a primer is to be lowered into a blasthole by means of the lead wires, safety fuse, detonating cord or signal tube, the mass of the primer shall not exceed one-third of the breaking strain of the weaker component. If the breaking strain is not known, the mass of the primer shall not exceed the following:

(a) Detonating cord .... 12.5 kg.

(b) Lead wire .... 2 kg.

(c) Signal tube .... 2 kg.

(d) Safety fuse ....manufacturer's or supplier's recommendations.

When detonators are used as the initiating medium, they shall be attached to the primer cartridge in such a way that during loading no tension is applied to the safety fuse, lead wires or signal tube where they enter the detonator.

NOTES:

1 It is essential that manufacturer's or supplier's recommendations be strictly adhered to, to ensure that the initiating medium is of sufficient strength to initiate the primer cartridge.

2 Side initiation of the principal charge or stemming disruption may occur with detonating cord downlines.

3 Additional information on the preparation of primers is provided in Appendix D.

4 It is essential that manufacturer's recommendations be strictly adhered to, to ensure that the initiating medium is of sufficient strength to initiate the primer cartridge.

6.4 BOOSTERS/PACKAGED PRODUCTS

6.4.1 Cutting of cartridges

The cutting of cartridges to reduce the mass charge, or for any other reason, is not recommended unless manufacturer's instructions regarding the cutting of cartridges or other specialist packaged products are followed.

6.4.2 Location of primer

The primer shall be located in the blasthole in such a position as to minimize the risk of non-initiation through being cut off during the blasting sequence.

In the case of surface blasting, the primer should be placed in the bottom part of the explosive column in the blasthole with the detonator facing the charge. In deep blastholes, mid and top priming may be included was well as bottom priming.

NOTE: This sequence is intended to ensure initiation of the charge and that no unexploded explosive remains after firing.

6.5 SURFACE CHARGING

6.5.1 General requirements

Blastholes shall be loaded in accordance with the blast design and loading sequence. Each initiation system shall be adequately secured to prevent it from falling into, and subsequently being lost in, a blasthole.

If during the charging it is noticed that a blasthole deformity or loss of initiation system has occurred, the shotfirer shall be notified. The shotfirer shall then determine an appropriate course of action.

It is the responsibility of the shotfirer to ensure that the intended explosive products are loaded. The shotfirer should therefore monitor the deliveries to, and/or manufacture of explosives at, the blasting operation. Where the shotfirer is not satisfied that the intended products are being used, the shotfirer shall instigate appropriate corrective action, which may include the stoppage of loading.

6.5.2 Charging wet blastholes

6.5.2.1 *General*

Blastholes containing water should not be charged with explosives (for example ANFO), including initiation systems, whose performance is affected by the presence of water unless appropriate measures are taken to ensure that the explosive in use is not affected. Examples of such measures include sleeving, decking, de-watering, waterproofing or the use of waterproof explosives.

WARNING: THE USE OF PLASTIC-LINED OR PLASTIC-SLEEVED BLASTHOLES GREATLY INCREASES THE RISK OF ACCIDENTAL INITIATION BY STATIC ELECTRICITY.

NOTE: When selecting explosives for use in wet blastholes, the effect of water on the explosives should be considered where extended sleep time is planned or likely.

Where there are wet and dry blastholes, those that contain water shall be identified and clearly marked.

6.5.2.2 *Dewatering*

Where dewatering of blastholes is carried out, this activity shall be undertaken by a competent person.

SECTION 7 CHARGING

7.1 SAFETY PRECAUTIONS

Before charging commences, unauthorized personnel and machinery not involved with the blasting operations shall be removed from the area.

Warning signs shall be displayed advising that blasting operations are in progress.

NOTE: Information for signs used on public roads is provided in AS 1742.3 and AS 1743.

The following precautions should be observed during charging operations:

(a) In order to avoid delays and the consequent increased risk, all equipment required for the charging operation should be ready on site before charging commences. This includes adequate stemming and explosive materials.

(b) Appropriate records should be kept (see Appendix A).

7.2 PRECAUTIONS AT SITE

No work or vehicular activity, other than that associated with the charging operation, shall be performed within close proximity of a blasthole or initiation system. Where vehicular access is essential, special procedures shall be developed and implemented to prevent the vehicle damaging or initiating the blast.

If charging operations are occurring at more than one location at a particular site, adequate communication shall be maintained between each operation.

There shall be no smoking, naked lights, or machinery likely to generate heat or sparks within close proximity of any blasthole being charged. A risk assessment shall be conducted and controls implemented before machinery that is likely to generate heat or sparks is used within this safety distance.

In normal operations, charging shall not begin unless it is practicable to complete the charging and firing operation on the same day, and in no circumstances shall charged blastholes be left unattended or unsecured. Where charging operations may continue over a period of more than one day, a risk assessment shall be conducted and any necessary control measures shall be implemented.

7.3 BLASTHOLES (CLEANLINESS)

Blastholes shall be thoroughly cleaned of all loose material before charging. If not charged immediately, blastholes shall be plugged or otherwise protected to prevent debris entering the blasthole.

NOTE: Each blasthole should be examined before insertion of the charge.

7.4 INSERTION OF CHARGE

7.4.1 Procedure

Undue force shall not be used to insert the charge in the blasthole. Except in the case of deck charging, care shall be taken to avoid the presence of extraneous matter between cartridges.

NOTES:

1 If an obstruction is encountered in a blasthole after charging of that blasthole has begun, the obstruction may be removed using either a flow of water or water and compressed air. If the obstruction cannot be removed, charging, which should include an additional primer, may continue provided the charge is not too near the collar and therefore result in unwanted noise or fly.

2 Blastholes that are charged with a primer above an obstruction can give rise to additional noise, toe, and vibration problems if multi-row firing is used.

3 Safety fuses, lead wires, detonating cords or signal tubes should be secured firmly at the collars of blastholes to prevent their ends from being drawn down and lost in the blasthole during the remainder of the charging operation.

7.4.2 Free-flowing granular explosives

7.4.2.1 *General*

When using free-flowing granular explosives, care shall be taken to ensure continuity of the charge.

NOTE: For gravity-fed situations, this will normally be ensured if the angle of the blasthole is limited to a maximum of 30° from the vertical. Free-flowing granular explosives may be pneumatically charged into blastholes at any angle.

7.4.2.2 *Protected-type detonators*

Protected-type detonators shall be used when pneumatic charging and electric firing of free-flowing granular explosives are employed.

NOTE: Because of the possibility of static discharge causing premature detonation—

(a) electric detonators should not be placed in plastic tubes; and

(b) free-flowing granular explosives should not be poured or pneumatically loaded into paper or plastic liners containing detonators.

7.4.3 Cutting of cartridges

Where practicable, only whole cartridges shall be charged into blastholes.

Where it is essential and safe to cut nitroglycerine-based cartridges to provide a correct mass charge, such cartridges shall not be cut against a hard, metallic, or rock-like surface.

7.4.4 Location of primer

The primer shall be located in the blasthole in such a position as to minimize the risk of non-initiation through being cut off during the blasting sequence.

NOTE: In general, the primer should be placed in the bottom part of the explosive column in the blasthole with the detonator facing the charge. In deep blastholes, mid and top priming may be included as well as bottom priming. This sequence is intended to ensure initiation of the charge and that no unexploded explosive remains after firing.

7.4.5 Pumpable explosives

When delivering pumpable explosives into a blasthole, controls shall be implemented to ensure the following:

(a) The explosive is mixed according to the manufacturer's specifications.

(b) The operator remains at the control panel or control device.

(c) Spillage does not occur.

(d) Overfilling of the blasthole does not occur.

7.5 STEMMING

7.5.1 Stemming material

A wide variety of material may be used as stemming material, and the requirements vary with the size of the blasthole and the site conditions.

NOTE: Appendix E, which covers flyrock and fly, gives guidance for choosing appropriate stemming material.

The following should be considered:

(a) In small diameter (less than 45 mm) blastholes, the stemming material may be soil, sand, drill cuttings or aggregate of a size no greater than one-tenth of the blasthole diameter.

(b) In large diameter (greater than 45 mm) blastholes, drill cuttings are often used; however, aggregate as in Item (a), is recommended.

(c) In wet blastholes, aggregate as in Item (a) is recommended as it sinks through the water, is self-tamping and interlocks well.

(d) Where blastholes are horizontal or are inclined upward from the collar, the stemming material may be preformed and, where necessary, wrapped in paper and held in position by a plug of wet clay. Alternatively, wet newspaper well tamped into the blasthole may be used.

(e) Where the potential exists for sulphide ore dust explosions, special requirements may apply.

(f) In reactive ground situations, it is not advisable to use drill cuttings as stemming material.

7.5.2 Tamping rods

Tamping rods of suitable length of wood or other non-metallic material shall be used. Metal ferrules, tips or connectors that may damage downlines or cartridges shall not be used. Where a tamping rod is used for inserting a charge, the ends shall be kept clean and square and the rod shall be thoroughly cleaned of any adhering grit.

7.5.3 Tamping of stemming material

Where required, stemming material shall be tamped as follows:

(a) Tamping with an appropriately made tamping tool shall be light at first, but as the blasthole becomes filled, the tamping pressure may be increased.

(b) For top-primed blastholes, tamping shall not begin until at least 150 mm of stemming material has been placed.

7.5.4 Precautions

Care shall be taken to ensure that the lead wires, detonating cord, signal tube or safety fuse connected to the primer are not damaged during the placing of stemming material and subsequent tamping.

NOTE: Safety fuses, lead wires, detonating cords or signal tube should be held firmly while the stemming is being placed in the blasthole, to prevent them from kinking.

7.6 BULLING

Where blastholes are to be bulled, suitable protective guarding shall be placed in front of the collar of the blastholes to reduce the danger of fly.

NOTES:

1 Where alternative methods are available, this method of blasting is not recommended as there is always the danger of heating in the blasthole and excess charging and prolonged excess noise.

2 Where a bulling charge is being fired, stemming is not generally used, but if it is, it should be water.

SECTION 8 METHOD OF INITIATION

8.1 GENERAL PROVISIONS

8.1.1 Risk management

Controls and procedures to assist in achieving an acceptable level of risk should be considered for the management of the following:

(a) Adverse weather conditions.

(b) Sleeping of shots.

(c) Fume minimization.

8.1.2 Allocation of responsibilities

Roles and responsibilities associated with the firing activity, including the shotfirer, shall be clearly established. Responsibilities to be assigned may include but are not limited to the following:

(a) Shot tie-in.

(b) Shot initiation.

(c) Sentry positioning.

(d) 'All-clear' determination.

(e) Misfire management.

(f) External/public communications.

(g) Environmental or condition monitoring.

(h) Emergency procedures.

8.1.3 Connections

Where required by the blast management plan, a documented firing sequence plan should be in use. This plan should include the following information:

(a) Identification of the initiation point.

(b) Identification of the control row.

(c) The delay times to be used within the blast, and their location.

(d) Method of initiation.

(e) Final inspection.

Where applicable, a method shall be developed to ensure that the firing sequence plan and procedures are explained to all persons involved in the connecting process, prior to commencement of connection. Controls shall be developed that minimize the occurrence of incorrect connections shall be developed. Incorrect connections can result in the following:

(i) Misfire.

(ii) Fly generation.

(iii) Excessive ground vibration or airblast.

(iv) Poor blasting performance.

8.2 METHOD OF INITIATION

8.2.1 Selection of initiation method

Careful selection of an initiation method shall be made following a risk analysis. Before selecting an initiation method, a risk assessment should include, but not be limited to, the following issues:

(a) Safety issues.

(b) Compatibility of initiation system with the charge.

(c) Environmental issues.

(d) Performance and reliability of initiation system.

(e) Economic considerations.

8.2.2 Electronic detonator systems

NOTE: Personnel using electronic detonator systems should undertake specific training in the use and handling of the particular manufacturer's product.

Manufacturer's warnings and instructions shall always be followed.

Safety precautions include, but are not limited to, the following:

(a) Components from different electronic systems or suppliers shall not be combined as misfires can result. This is due to the nature of the unique communication protocols and customized connectors of the various electronic blasting and initiation systems.

(b) Only wires, connectors, and coupling devices specified by the manufacturer shall be used.

(c) Wire ends, connectors and fittings, shall be short-circuited where required by the manufacturer and, as far as possible, kept clean and clear from dirt or contamination.

(d) Electronic detonators shall not be held while being tested or programmed.

(e) Manufacturer recommendations to protect electronic detonators from electromagnetic, radio frequency or other electrical interference sources shall be followed.

(f) Manufacturer's instructions when aborting a blast shall be followed. A minimum of 30 min shall be allowed before returning to the blast area after aborting the blast unless a manufacturer provides other specific instructions.

(g) Care should be taken when allocating delay times to ensure the intended blast sequence is implemented, otherwise this can result in misfires, fly, excessive airblast overpressure and ground vibration.

(h) Electronic detonator systems shall not be used during the approach and progress of an electrical storm. Personnel shall be withdrawn to a safe location.

Maintenance, as prescribed by the manufacturer/supplier, shall only be carried out by authorized personnel. Records of maintenance done on all equipment, including date and person carrying out the work shall be kept.

WARNING: ELECTRONIC DETONATORS ARE EXPLOSIVES AND THEY SHOULD BE HANDLED ACCORDINGLY.

8.2.3 Non-electric firing

8.2.3.1 *Signal tube*

Signal tube may be initiated by one of the following methods:

(a) A purpose-designed signal tube starter.

(b) A detonator of required strength.

(c) Detonating cord.

The hook-up shall be done in a manner that ensures intended initiation sequence. This may consist of signal tubes, detonating cords, or a combination of both. Connections and detonating cord charge weights shall be in accordance with the manufacturer's instructions.

NOTES:

1 For guidance on primers, see Appendix D.

2 For guidance on the use of detonating cords, see Paragraph F2, Appendix F.

Where detonators are used to initiate the signal tube, the last action should be to attach the initiating/starting detonator(s) to the trunkline or lead-in line.

8.2.3.2 *Safety fuse*

A match may only be used to light a single fuse. Where more than one fuse is lit, an appropriate type of fuse lighter shall be used.

NOTE: More than eight applications of a fuse lighter should not be made at any one initiation.

Devices used for the purpose of connecting the number of safety fuses used and firing them by means of a master fuse or igniter cord shall be of a type suitable and safe for their intended use.

Relative fuse lengths, or the lighting delay between fuses of equal length, shall be such that the shots are separated by sufficient time intervals to enable them to be accurately counted.

For safety fuses, the portion projecting from the blasthole shall not be coiled. In no case shall a fold or coil of fuse be pushed into the collar of the blasthole. If it is necessary to bend the safety fuse, bending shall be done in the direction of the original coiling and in no case to a radius of less than 75 mm. In multiple firing, separate fuses shall not be in contact except in a multiple fuse igniter.

NOTE: Safety fuses should not be used in well- or shaft-sinking operations unless they can be lit from outside the well or shaft, or an area assessed as safe.

8.2.3.3 *Detonating cord*

NOTES:

1 For guidance on the use of primers, see Appendix D.

2 For guidance on the use of detonating cords, see Paragraph F2, Appendix F.

8.2.4 Electric firing

8.2.4.1 *Electric firing with exploders*

8.2.4.1.1 *Exploders*

Exploders shall comply with the following requirements:

(a) *General* Storage batteries or dry cell batteries shall not be used as the direct source of firing energy unless contained in an exploder, where they shall be considered to be an integral part of that exploder.

Exploders shall be stored in a clean area free from moisture, oil and other contaminants.

The exploder shall be clearly marked to show its firing capacity in terms of either—

(i) the number of specified detonators connected in series; or

(ii) the overall circuit resistance.

At no time shall an attempt be made to fire circuits that exceed the rated capacity of the exploder.

(b) *Security of exploders* Prior to any loading commencing, the shotfirer shall ensure that the exploder is rendered and kept inoperative until required for firing. After firing, the shotfirer shall render and keep the exploder inoperative until required to fire the next shot or the exploder is stored.

(c) *Testing of exploder* The exploder shall be tested to the rated maximum capacity as set out in Paragraph B5.2, Appendix B. Such testing shall be undertaken in accordance with the manufacturer's or supplier's instructions where available or, in the absence of such instructions—

  (i) at frequent intervals during continuous use;

  NOTE: In normal conditions, testing of exploders at monthly intervals would be adequate.

  (ii) after an interval of non-use during operations; or

  (iii) when a loss of efficiency is suspected.

Additional requirements for exploders are provided in Appendix B.

8.2.4.1.2 *Firing cable*

The firing cable shall be of sufficient length to connect the lead wires of the detonators or connecting wires to the source of energy to be used (see Paragraph B7, Appendix B). The firing cable leading to the blasting location shall be short-circuited while the lead wires from the detonators are being connected. This short-circuit shall be located so that a premature explosion would be harmless to the person opening the short-circuit. The short-circuit shall not be removed until the blasting area has been cleared and the cable is about to be connected to the exploder and shall be replaced immediately after the firing switch has been opened; the firing cable shall then be removed from the exploder.

NOTE: The firing cable should be checked visually for damage and electrically with a circuit tester (see Paragraph B4, Appendix B) for continuity, short-circuits and resistance.

8.2.4.1.3 *Electrical connections*

The following requirements for electrical connections shall be observed:

(a) *Connection of lead wires to cables* Lead wires shall be connected to the firing cables with suitable connections.

(b) *Connection of cables to exploder* The firing cables shall not be connected to the exploder until the blasting area has been cleared.

(c) *Electrical contact* Electrical contact shall not be made to the exploder until immediately before firing and shall be disconnected immediately afterwards.

(d) *Re-use of cables* The firing cables or associated wiring used for firing shots at one working place shall not be used for firing shots in another working place until all precautions and tests have been taken to ensure that such firing cables or wires have no electrical connection with the leads from the first working place.

8.2.4.1.4 *Electrical firing circuit*

The electrical firing circuit shall provide a continuous electrical path between the exploder and the detonators.

NOTE: Information of firing circuit connections is provided in Appendix F.

8.2.4.1.5 *Testing*

Before connecting the firing circuit to the exploder, the detonating circuit and firing cables shall be tested from a safe position and with the area cleared.

NOTE: Recommendations for the testing of the firing circuit are provided in Appendix F.

8.2.4.2 *Mains firing*

8.2.4.2.1 *General*

A completely insulated and unearthed blasting circuit shall be provided. After determining the type of circuit to be used, voltage and current shall be capable of initiating the number of detonators in the circuit.

8.2.4.2.2 *Firing switch*

The firing switch shall be protected so that, when in the 'off' position, there is—

(a) a total absence of current between the firing point and the blasting location; and

(b) no current leakage into the firing mains.

The firing switch and any other switch necessary for compliance with this Clause shall each be placed in a fixed locked box, each box being so constructed that it cannot be shut unless the switch is in the safety position. Security of each box shall be ensured by use of an appropriate management system that includes shift-change responsibilities.

8.2.4.2.3 *Firing cable*

The firing cable shall be of sufficient length to connect the lead wires of detonators or connecting wires to the source of energy to be used. The firing cable leading to the blasting location shall be short-circuited while the lead wires from the detonators are being connected. This short-circuit shall be located so that a premature explosion would be harmless to the person opening the short-circuit. The final short-circuit shall not be removed until the blasting area has been cleared and the final cable connection is about to be made. The short-circuit shall be replaced immediately after the firing switch has been opened, the firing cable removed from the power source and the firing box closed and locked.

NOTE: The firing cable should be checked both visually and electrically for both broken circuits and short-circuits and any damage, prior to commencing the charging.

8.2.4.2.4 *Electrical connections*

The following requirements for electrical connections shall be observed:

(a) *Connections of lead wires to cables* The lead wires shall be connected to the firing cables with suitable connections.

(b) *Connection of cables to power supply* The firing cables shall not be connected to the source of power until the blasting area has been cleared.

(c) *Electrical contact* Electrical contact shall not be made to the firing switch until immediately before firing and shall be disconnected immediately afterwards and the box locked.

(d) *Re-use of firing cable* The firing cable or associated wires used for firing shots at one working place shall not be used for firing shots in another working place until all precautions and applicable tests have been taken to ensure that such firing cables or associated wires have no electrical connection with the leads from the first working place.

8.2.5 Remote firing

8.2.5.1 *General*

The sequence for obtaining a firing output shall be able to be suspended, abandoned and terminated at any point up to the signalling of blast, without causing the initiation of explosives.

No change to supply of power to any part or whole of the remote firing system shall cause initiation of explosives. Such changes include, but are not limited to the following:

(a) Loss of power.

(b) Application of power.

(c) Changes or modulation (periodic changes) to any parameter of power supply (such as voltage or current level, frequency, shape or gradient, fluid pressure, etc.).

The following applies to any part of the remote firing system leading to the firing cable or signal tube:

(i) No fault or series of faults shall produce firing output or cause initiation of explosives.

(ii) Any single fault shall be detected and—

  (A) the system shall be put in a safe mode; and

  (B) successive use of the system shall be prevented such that accumulation of faults shall not be possible.

(ii) No failure shall cause dependent (subsequent) failures leading to initiation of explosives.

No external interference to any part of the remote firing system leading to the firing cable or signal tube shall produce firing output or cause initiation of explosives.

No casual connection (or loss of connection) between exposed conductors (including momentary connection between pins on non-matching connectors) shall cause initiation of explosives.

NOTE: The use of remote firing can create hazards specific to remote operation and increase the risks from other hazards present in the working environment or associated with the use of equipment and explosives. Therefore, risk assessment requires a systematic approach to cover the full and complete field of possibilities in an exhaustive manner and to adequately treat all hazards according to their ranking.

8.2.5.2 *Equipment*

The remotely operated exploder shall be fitted with effective facilities to warn of—

(a) selection of the exploder to remote form of operation; and

(b) the intention to initiate explosives with it.

NOTE: Figures 8.1 and 8.2 give schematic representations of remote firing systems.

Effectiveness of facilities shall be determined in the assessment of safety risk.

The exploder shall not produce a firing output or cause initiation of explosives when an attempt is made to control it from controllers or sources other than by those dedicated, and designed to do so.

All portable remote controllers and portable remote exploders shall be capable of withstanding a free vertical fall of 1 m onto a rigid concrete surface without damage that would otherwise cause the inadvertent initiation of explosives.

All remote controllers and remote exploders shall be capable of withstanding an impact test of 20 J as set out in AS/NZS 4240, without damage that would otherwise cause the inadvertent initiation of explosives.

NOTE: A locked physical barrier that prevents access to the operating mechanism and terminals is recommended.

Marking of the remotely operated exploder should include—

(i) information that is remotely controlled; and

(ii) identification of the control unit used to operate it remotely.

Marking (display) of the remote controller should include—

(A) identification of the remotely operated exploder under control; and

(B) information about system response lag.

Remote firing equipment should only be repaired or overhauled under the supervision of a competent person, working in an accredited/certified workshop and using relevant documentation.

8.2.5.3 *Procedures*

The remotely operated exploder shall be placed in a safe position.

The firing cable or signal tube shall not be connected to the remotely operated exploder until all personnel in the blasting area, including the shotfirer, are in a safe position.

From the remote control unit it shall not be possible to—

(a) place the exploder into a remote mode of operation; and

(b) change the exploder's state from SAFE to ON.

These functions shall be performed only manually and at the exploder.

An assessment about the safety risk should be made prior to—

(i) commissioning and acceptance of a remote firing system for implementation; and

(ii) any changes being made to a remote firing system.

The assessment should identify the risks, estimate the likelihood and magnitude of their consequences, produce a list of controls (equipment, procedures, actions, etc.) for treatment (elimination, reduction, transfer, management) of the risks and nominate personnel responsible for effective implementation of these controls.

Personnel should not be involved in the repair or use of a remote-controlled firing system until suitably trained to a current industry competence level for the particular task.

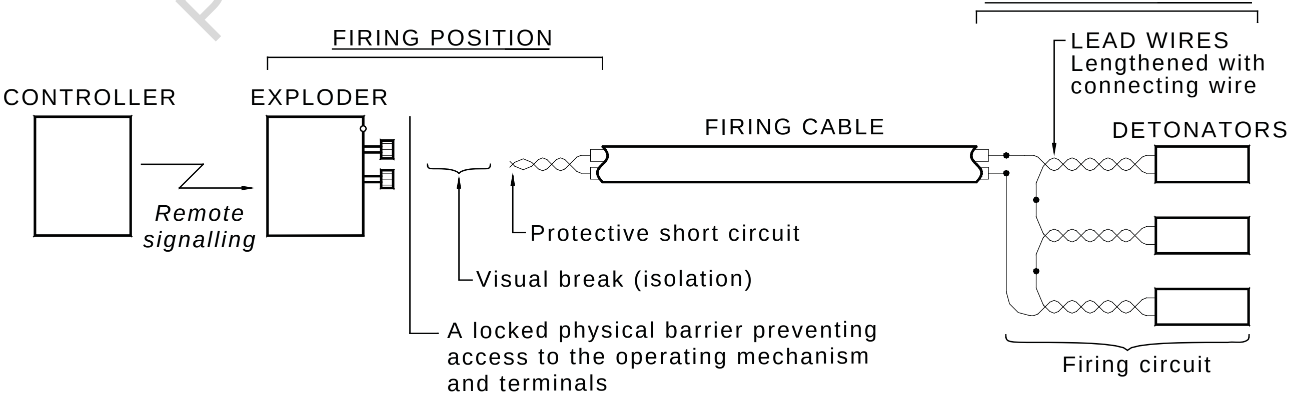


FIGURE 8.1 ELECTRIC REMOTE FIRING

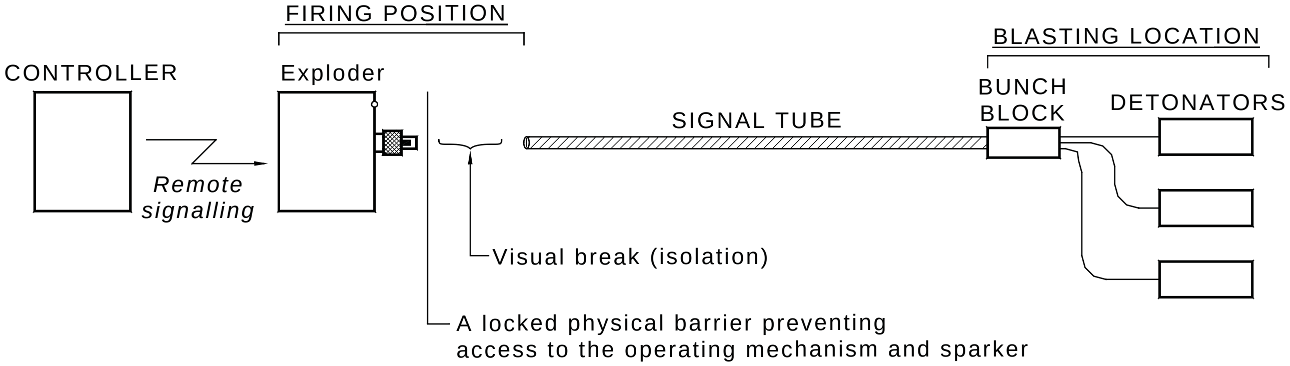


FIGURE 8.2 NON-ELECTRIC REMOTE FIRING

8.3 FIRING

Precautions need to be taken prior to and during firing to ensure the safety of persons and property.

The blast management plan should consider, for example, the following:

(a) Sentry selection and training.

(b) Determination and establishment of an exclusion zone around the shot prior to, during and after firing.

(c) An effective communication system between the shotfirer, the sentries and other necessary persons.

(d) A warning system to ensure all persons working around a shot, but outside the exclusion zone, are informed of the intended blast. This system may include a blasting siren.

(e) Where applicable, a method of informing, co-ordinating and minimizing the impacts on the general public shall be established (e.g., road, railway or flight path disruptions).

(f) The final warnings issued by the shotfirer before the shot is fired.

(g) Provisions for a safe place for the shotfirer to initiate the shot.

NOTE: Where an audible warning device is used, it should produce a sound that is recognizable and clearly different from any other sound that might be used for warning or other operational signals on the work site and sufficiently loud to give adequate warning to those likely to be affected by the blast. A modulated frequency siren is normally suitable.

SECTION 9 POST BLAST PROCEDURES

9.1 GENERAL SAFETY CONSIDERATIONS

9.1.1 Blast management plan

The blast management plan should specify procedures to be implemented, which allow an inspection of the blast area following blasting activities to determine when and if it is safe for routine operations to continue. These procedures should include, but not necessarily be limited to, the following:

(a) Assessment of the blast site prior to a post-blast inspection (see Clause 9.1.2).

(b) Minimum waiting time prior to conducting the post-blast inspection.

(c) Who may enter the exclusion zone prior to conducting the post-blast inspection.

(d) Prohibition of all other people from entering the exclusion zone prior to the 'all clear' being sounded.

(e) The meaning of the 'all clear'.

(f) The means of sounding the 'all clear'.

NOTE: If a siren or other communication means has been used to warn people of the blasting activity, this warning should continue until relevant activities specified in Clause 9.3 have been safely concluded.

9.1.2 Assessment prior to a post-blast inspection

Before proceeding to the blast site to carry out an inspection, the shotfirer or other competent person shall make an assessment to ascertain if it is safe to do so. The assessment shall include, but not necessarily be limited to, consideration of the following factors:

(a) Whether fume dispersal has occurred.

(b) Whether mechanical ventilation is operating (where used).

(c) Whether dust dispersal/settlement has occurred.

(d) The identification of any apparently unstable ground.

(e) The stability of buildings and other structures.

(f) The safety and suitability of access and egress.

(g) Aspects of the blast that may indicate that not all of the charges have been initiated.

(h) In the case of a misfire, or a suspected misfire, whether the minimum waiting time has been observed (see Section 10).

(i) The availability of a competent person to inspect for safety, ground or material that did not move as intended.

9.2 SHIFTWORK

Where shiftwork is in progress and firing has taken place at the end of a shift, the shotfirer shall inform the person responsible on the next shift of all applicable details of the shot.

9.3 ELECTRIC FIRING

9.3.1 Electric firing with exploder and electronic firing

Immediately after the current has been applied to the circuit and before any person returns to the blast site, the shotfirer shall—

(a) remove the key or handle from the exploder;

(b) disconnect the firing cable from the exploder; and

(c) short-circuit the ends of the firing cable.

NOTE: Item (c) may not be necessary for electronic firing.

In addition, the key or handle shall be retained in the possession of the shotfirer or other competent person who will be inspecting the blast site, until the 'all clear' is given.

9.3.2 Mains firing

Immediately after the current has been applied to the circuit and before any person returns to the blast site, the shotfirer shall—

(a) disconnect the power source to the firing box;

(b) disconnect the firing cable from the energy source;

(c) short-circuit the ends of the firing cable; and

(d) close and lock the firing box (or energy source).

In addition, the key or handle shall be retained in the possession of the shotfirer or other competent person who will be inspecting the blast site, until the 'all clear' is given.

NOTE: When a short-circuit box is used and it is adjacent to the firing box, it should also be locked and the key retained.

9.3.3 Remote firing

Immediately after the remote control unit has been activated to signal the exploder to energize the circuit, and before any person returns to the blast site, the shotfirer shall—

(a) place the remote control unit in the 'SAFE' mode and lock the unit;

(b) after assessing the general safety considerations, and when it is assessed to be safe to return to the exploder, disconnect the firing cable or signal tube from the exploder; and

(c) short-circuit the ends of the firing cable.

In addition, the key or handle shall be retained in the possession of the shotfirer or other competent person who will be inspecting the blast site, until the 'all clear' is given.

9.4 POST-BLAST INSPECTION

The purpose of a post-blast inspection is to ascertain if it is safe for personnel to return to the blast site and for routine operations to resume.

The extensive variables associated with not only the type of blasting operation but also the location of the operations would necessitate specific rather than general post-blast procedures to be included in the blast management plan. The procedures for consideration should include but not be limited to the following:

(a) Whether there is a need for more than one person to return to the shot for the inspection.

(b) Procedures to be adopted if the inspection reveals that the 'all clear' into the exclusion zone cannot be given, including the communications mechanism of the 'all clear' or otherwise.

(c) Determination that oxygen, fumes and dust are at acceptable levels.

(d) Continuous inspection procedures during the approach to the post-blast site that might identify unusual or abnormal results indicating possible hazards.

(e) Whether there is a need to wash down/or scale (bar down), especially in underground workings.

(f) Identifying a misfire or butt and the means of clearly marking misfires or butts.

9.5 SITE HOUSEKEEPING

The shotfirer shall ensure that the site is left in a safe condition after every blast. Consideration should be given to the removal and disposal of those items that could be mistaken by the public to indicate the presence of explosives.

SECTION 10 MISFIRES

10.1 DETERMINATION OF MISFIRES

To determine a misfire, the shotfirer or other competent person shall inspect the blast area. Signs that a misfire could have occurred include, but are not limited to, the following:

(a) No detonation is observed (which implies no visual, audible or ground movement/vibration evidence).

(b) Undisturbed ground or material is observed within the blast during the detonation or inspection.

(c) Cut-offs.

(d) Uninitiated explosive, including explosive product, found during excavation.

(e) If, when using safety fuse, the number of shots counted is less than the number of blastholes or groups of blastholes fired, or if there is a disagreement on the count of shots fired, a misfire is to be assumed.

(f) If safety fuse, detonating cord, or signal tube uninitiated and protruding from is a blasthole or butt that was intended to have been fired, that blasthole is to be treated as a misfire.

(g) If lead wires are exposed in a portion of a blasthole that was intended to have been fired, that blasthole is to be treated as a misfire.

(h) Unless butts or remaining portions of blastholes have been shown to be free of explosives, they are to be treated as misfires.

(i) Identification of unexploded explosive after the ‘all clear’ has been given and site work has recommenced.

10.2 MISFIRE MANAGEMENT SYSTEM

The blast management plan shall include a misfire management system, which shall provide for the responsible and safe management of misfires. Identification of misfires may be achieved in the following situations:

(a) Immediately after the initiation of the blast and before the post-blast inspection.

(b) During the post-blast inspection.

(c) During or after the removal or movement of blasted material.

The misfire management system shall provide for, but not be limited to, the following:

(i) Methods for locating misfire(s).

(ii) Procedures for marking and identifying misfire(s).

(iii) Procedures to establish and maintain an exclusion zone related to the misfire(s).

(iv) The introduction, removal or control of potential detonation or ignition sources.

(v) Communication/notification of the misfire(s) to relevant persons.

(vi) Procedures for misfire treatment.

10.3 TREATMENT OF MISFIRES

10.3.1 General

All identified misfires shall be made safe. The manner in which a particular misfire is to be treated may vary, but an underlying approach should be established in the misfire management system.

NOTE: Some regulatory authorities require that misfires be reported.

10.3.2 Waiting intervals

Where explosive hazards are the only hazards present, and other hazards, such as lingering dust and fumes, are not present, the following minimum waiting shall be observed:

(a) With the exception of safety fuse initiation, the minimum waiting interval is 5 min or such greater interval as determined in the misfire management system.

(b) Where a charge or detonator that is intended to be directly initiated by safety fuse is identified as having failed to have been initiated, no person is to approach the misfire until an interval of 30 min has elapsed, or such greater interval as determined in the misfire management system.

Where other hazards are present, for example, lingering dust and fumes, a longer waiting time may be needed.

10.3.3 Treatment

Options for the treatment of misfire(s) include, but are not limited to, the following:

(a) Refiring.

NOTES:

1 If lead wires are protruding from a blasthole, they should be short-circuited and coiled into the blasthole collar until refiring procedures are implemented.

2 It may be necessary to increase the size of the exclusion zone.

3 Refiring should only be done after taking into account remaining protection systems to minimize environmental and safety impacts.

(b) Removal of the stemming (see Clause 10.3.4) followed by repriming, re-steming and initiation.

(c) Removal of the explosive from the blasthole(s) by flushing the blasthole with water, or water and air, after any stemming material has been removed.

NOTE: Environmental impacts should be considered and addressed before explosive products are flushed.

(d) Mechanical or manual removal of the explosive.

(e) Drilling, charging and initiating a new blasthole in the vicinity of the misfire(s) (see Clause 10.3.5).

After treating the misfire(s), work shall not resume at that location until the shotfirer or other competent person has made a thorough search for any explosive from the misfired charge.

Recovered explosive shall be disposed of in a suitable and safe manner by a competent person.

No person shall leave unguarded, abandon, discard or otherwise neglect to safely dispose of, or ensure the security of, any explosive recovered in the treatment of misfires.

10.3.4 Removal of stemming

Stemming may be removed by applying water under pressure, or a mixture of water and compressed air, through a non-ferrous blowpipe or hose.

NOTES:

1 Other methods may become available and these may be used once a risk assessment has been made.

2 The use of compressed air alone is discouraged. Where it is used, special precautions should be taken to minimize the dangers from static electricity and impact.

3 Where water under pressure or compressed air is not available, the stemming may be sludged out by the use of water and a tamping rod.

4 During stemming removal, detonators and explosives are susceptible to accidental detonation.

5 Consideration should be given to the diameter of the blowpipe or hose in relation to the blasthole to allow free-flow of the materials being removed. This is to ensure that there is no excessive pressure build-up in the blasthole.

10.3.5 Firing of a new blasthole in vicinity

Where a blasthole has been previously bulled, the relieving blasthole method shall not be used.

If it is not possible or practicable to treat the misfire(s) by the methods described in Clause 10.3.3(a) to (d), a relieving blasthole may be drilled as parallel as possible to the original blasthole, then charged and fired. Before any relieving blasthole is drilled it shall be established that the drill will not contact explosives.

To complete this operation the following procedure may be effective, but will be subject to other controls determined by risk analysis:

(a) Refer to the blast plan to identify details of the misfired blasthole(s), (e.g., depth, deviation, orientation).

(b) To prevent drilling into a misfire, clearly mark the blasthole and effectively block the collar of the misfired blasthole (e.g., by the insertion of a wooden plug).

(c) Drill the relieving blasthole at a distance that is sufficient to prevent any part of the drill string from entering any part of the misfired blasthole.

NOTE: Where practicable, a remotely operated drill rig should be used to minimize the risk of injury to persons.

With larger and longer blastholes, the distance between the misfired blasthole and the relieving blasthole shall be increased as circumstances warrant.

SECTION 11 DESTRUCTION OF DEFECTIVE AND SURPLUS EXPLOSIVES

11.1 GENERAL PROVISIONS

11.1.1 Instigation

Explosives that are considered unsafe for normal transport, storage or use shall be destroyed. Explosives that are surplus may be destroyed. Persons intending to dispose of defective explosives shall seek advice from the manufacturer where it is available. Where such advice is not available, destruction of these explosives shall be in accordance with this Section.

NOTE: Appendix G gives information on some forms of deterioration of explosives.

11.1.2 Records

Records shall be kept of quantities and types of explosive destroyed, and the destruction methods employed.

11.1.3 Residues

The residue from explosives destroyed by burning may be poisonous to livestock and wildlife. It shall be buried or otherwise disposed of in accordance with applicable environmental legislation.

11.2 METHODS OF DESTRUCTION

11.2.1 General

Explosives shall not be abandoned, thrown away, buried, discarded or placed with garbage.

Before commencing to destroy explosives, an exclusion zone shall be established and made secure.

Destruction of explosives shall be carried out under the control of a competent person.

NOTES:

1 For guidance on whether to destroy explosives not mentioned in this section, the manufacturer, supplier or the regulatory authority should be consulted.

2 Explosives that show evidence of serious exudation are likely to be unstable.

3 When serious exudation is a problem or if large quantities of explosives are to be destroyed, the appropriate regulatory authority and the supplier of the explosives should be contacted.

11.2.2 Explosives other than detonators

11.2.2.1 *General*

Explosives other than detonators shall be destroyed in accordance with Clauses 11.2.2.2, 11.2.2.3 or 11.2.2.4, as applicable.

11.2.2.2 *Burning*

Explosives may be destroyed by burning under the control of a person competent in the destruction of explosives.

It is possible to destroy the following types of explosives by burning:

(a) Cartridged explosives—nitroglycerine-based, watergel, and emulsion types.

(b) Cast boosters.

(c) Detonating cord.

(d) Safety fuse.

(e) Igniter cord.

The following shall not be destroyed by burning:

(i) ANFO.

(ii) Ammonium nitrate.

(iii) Bulk emulsions.

(iv) Bulk watergels.

(v) Explosives contained in rigid containers other than cardboard.

NOTE: A suggested procedure for burning explosives is provided in Appendix H.

11.2.2.3 *Detonation*

Explosives may be destroyed by detonation, provided that a fresh priming charge is used and no detonators are inserted into deteriorated or previously charged explosives.

Explosives shall not be detonated on ston y ground, in a shallow hole in such ground, or on an area where debris is likely to become missiles (see Note). The extent of the spread of such fly or flyrock will be proportional to the quantity of explosives being destroyed and the nature of the ground and debris. These factors should be considered when determining the exclusion zone. For this reason, explosives should be detonated in sand or earth free from stones.

NOTE: Missile damage can be expected over an extensive distance.

11.2.2.4 *Dissolving in water*

Small quantities of water-soluble explosives (e.g., ANFO) may be destroyed by immersion in buckets or drums of water. Alternatively, water-soluble explosives may be spread on the ground and watered in.

11.2.3 Detonators

Small quantities of detonators may be destroyed by one of the following methods:

(a) *Detonation* Detonators may be destroyed by detonation by either placing them in a hole with a suitable primer above and in contact with them, or by taping them to a primer or a length of detonating cord.

(b) *Burning* Detonators may be destroyed by burning in a furnace specially designed and constructed for the purpose.

NOTE: Some regulatory authorities require furnaces to be approved.

Where there is serious deterioration of detonators or large quantities of detonators need to be destroyed, the regulatory authority and the supplier shall be contacted.

11.2.4 Other explosives

For methods of destroying explosives not mentioned above, the manufacturer shall be consulted.

SECTION 12 SPECIAL CONSIDERATIONS

12.1 EXTRANEOUS ELECTRICITY

12.1.1 General

Where electric detonators are used to initiate explosive charges, they shall be used at such distances from sources of electromagnetic radiation that a substantial factor of safety is provided against the possibility of induced ignition of the detonators from such sources.

NOTES:

1 Additional information and guidance on extraneous electricity is provided in Appendix I. Table I1 sets out recommendations for minimum distances from sources of radio frequency radiation.

2 Electrical detonator leads should be short-circuited by twisting together the bared ends, until immediately prior to use.

12.1.2 Atmospheric electrical activity

If there is evidence of any form of atmospheric electrical activity or disturbance, on-site manufacturing operations, and surface and shallow underground blasting operations shall be suspended. Such operations shall not be resumed until the electrical disturbance has passed.

12.1.3 Direct contact with electrical conductors

Where firing cables or wires are used in the vicinity of electrical power, communications or lighting cables, adequate precautions shall be taken to prevent any firing cables or wires from coming into contact with such conductors before, during, or after firing.

12.1.4 Induced currents and stray currents

Adequate precautions shall be taken to prevent premature detonation due to capacitive and inductive coupling from high voltage lines, and from stray currents.

NOTE: As a guide, electric firing should not be used within 100 m of power lines with voltages in excess of 20 000 V.

12.1.5 Static electricity

Adequate precautions shall be taken to prevent premature explosion due to the build-up of static electrical charges. The following situations can contribute to this phenomenon:

(a) Loading explosives in dust storms and snowstorms.

(b) Moving conveyor belts.

(c) Pneumatic loading of free-flowing granular explosives or sand stemming into blastholes.

(d) Pouring free-flowing granular explosives into paper or plastic cartridges or blasthole liners.

(e) Low humidity or freezing conditions.

NOTE: Additional information on hazards due to static electricity are provided in Paragraph I5, Appendix I.

12.2 GROUND VIBRATION AND AIRBLAST OVERPRESSURE

Where blasting is carried out in proximity to buildings or structures, ground vibration and airblast overpressure shall be kept within limits related to the probability of damage and human discomfort.

NOTE: Recommended maximum levels for ground vibration and airblast overpressure are provided in Appendix J, together with additional information and guidance.

12.3 FLY

Where protection from the possibility of fly is necessary, blasting mats or other suitable controls shall be used.

Unconfined plaster or blister shots shall be permitted only where drilling of the rock to be blasted or other methods of fragmenting the rock are impracticable. Noise levels from all types of blasting will have to comply with the requirements of the appropriate regulatory authority.

NOTE: Guidance on the causes and prevention of fly is provided in Appendix E.

12.4 BLASTING UNDER WATER

12.4.1 Precautions

For blasting under water, no blast shall be fired when any person is in the water in the vicinity of the operations. Additional care shall be taken in waters such as estuaries or near beaches as the pressure pulse effects are more pronounced in water less than 10 m deep.

NOTE: Attention is drawn to the fact that blasting may not take place underwater without the permission of the appropriate regulatory authority.

Concussive effects and exclusion zones may be estimated for unconfined charges from the following equation:

$$P = 55 \times 10^3 \frac{m^{1/3}}{R} \qquad \text{. . . 12.4.1}$$

where

P = peak pressure, in kilopascals

m = mass of explosives, in kilograms

R = distance from charge to point affected by pressure, in metres

For confined blasthole charges underwater (P_c) (confined charge) may be estimated as 0.4 times the peak pressure. It is recommended that confirmation of such estimates be sought by monitoring a test shot(s) or other suitable means.

The recommended maximum peak pressure for human and animal exposure to underwater blasting is 40 kPa. Peak pressures in excess of 40 kPa can cause serious injury or death.

12.4.2 Detonators

Standard electric or electronic detonators with plastic-coated wire shall not be used at depths exceeding 30 m unless specified by the manufacturer or supplier.

NOTES:

1 Submarine, electric or special delay detonators should be used at depths greater than 30 m.

2 Detonating cord initiated by an electric detonator may be used but safety fuse should not be used underwater.

3 Water-resistant explosives, which would be expected to remain unaffected by a 24 h immersion but would be rendered inert by a larger period of immersion, may provide for greater safety. Care should be exercised in the location of detonators to avoid misfires and to facilitate recovery in the event of a misfire. Cast boosters should be avoided unless the explosive is booster sensitive at the depth and temperature of water in which the explosive is to be detonated.

12.4.3 Junctions

Joints shall be made before the cable is lowered. Joints in wires leading to detonators shall be thoroughly waterproofed such as by wrapping with insulating tape and treating with a sealing compound, care being taken to ensure that all joints have sufficient mechanical strength for the purpose for which they are intended.

12.4.4 Exploder key or handle

The means of operating the exploder shall remain in the possession of the person placing the charge while that person is submerged. In addition, live electrical equipment in the immediate vicinity of the exploder and firing cable shall be adequately isolated.

12.5 USE OF EXPLOSIVES IN AN ATMOSPHERE GREATER THAN ATMOSPHERIC PRESSURE

12.5.1 General

The use of explosives in an atmosphere greater than normal atmospheric pressure, created for the purpose of preventing inflows, presents a number of issues that would not normally be experienced in general use and need to be considered. Such issues include the following:

(a) The mass of oxygen per cubic metre in the air is greater.

(b) If the breathing medium being used by the workers has a percentage of oxygen greater than 21%, the mass referred to in Item (a) is even higher.

NOTE: This increased oxygen level is sometimes used to increase the working time of a worker without the need for decompression.

(c) The volatility of flammable/explosive gases and other flammable materials is increased proportional to the increased working pressure and oxygen content. Gases may not be released until or during initiation of a shot.

12.5.2 Storage

Explosives and detonators shall not be stored in an atmosphere greater than atmospheric pressure (see Clause 12.5.1).

12.5.3 Transport into working chamber

Explosives and detonators shall be taken into the working chamber in a receptacle that is suitable and safe for its intended purpose.

Only those persons required to transport the explosives into a chamber shall be allowed into an airlock. No other material or equipment shall be simultaneously taken into the working chamber with the explosives.

NOTE: Both explosives and detonators may be transported in the same container, provided that there is a division between the compartments and the lead wires are effectively short-circuited.

12.5.4 Method of initiation

12.5.4.1 *Explosives and initiation systems*

When deciding which explosives and initiation systems are to be used, the following criteria apply:

(a) Pilot drilling ahead and testing for flammable gases shall be considered.

(b) Deflagrating explosives or safety fuse initiation systems that incorporate deflagrating explosives shall not be used.

(c) The initiation system shall be able to be initiated from outside the compressed (air) environment.

(d) Explosives shall be suitable and safe for use in this environment. Manufacturer's recommendations should be sought.

(e) Consideration shall be given to the use of permitted explosives and detonators in strata that is likely to contain flammable gas irrespective of whether or not flammable gases are detected.

12.5.4.2 *Electrical firing*

Where charges are to be fired electrically, and where pumps and lights are in use, there shall be no cables or power within 30 m of the face being charged, and only lamps with a completely insulated power source shall be used, e.g., miner's cap-lamps.

12.5.5 Testing of electric detonators

Each electric detonator to be used shall be tested for continuity and resistance outside the working chamber.

The completed circuit and the firing cable shall also be tested from outside the working chamber.

NOTES:

1 See Appendix F for a suitable test method.

2 Electric detonators must not be confused with electronic detonators.

12.5.6 Effect of increased gas pressures on structural integrity

Initiating explosives generate huge volumes of gases in a negligible space of time and this increases pressures accordingly. Engineering detail should be sought as to the capability of bulkheads, relief valves and other analogous fixtures forming the seal(s) of the compressed air section to withstand the increased pressures that are generated by the initiated explosives. A maximum weight (not MIC) of explosive may need to be imposed and strictly enforced.

12.5.7 Firing, before and after

12.5.7.1 *Personnel to be withdrawn*

When charging is completed within the working chamber, all personnel shall move to safety prior to the detonation of the blast.

Blasts shall be initiated from outside the working chamber.

NOTES:

1 Before exploding a charge in a working chamber of a caisson, air should be blowing freely past the cutting edge where possible.

2 Where two or more shafts or tunnels are being excavated, either adjacent or towards each other (such as in small 'pot and drive' tunnelling operations), and the two crews are not in direct visual contact with each other, then the adjacent excavation crew should leave their excavation and retire to a safe place prior to the face-charging crew commencing charging the face, and they should not return to their own excavation until firing has been completed and the 'all clear' given.

12.5.7.2 *Airflow*

On detonation of the blast, air shall be exhausted from as near the face as possible to ensure that hazardous products generated from the blast are reduced to safe levels before any persons are allowed re-entry. At the same time, the rate of admission of air to the working chamber shall be increased so that an air velocity of not less than 7 m/min is maintained through the working chamber. The air pressure in the working chamber shall not be permitted to rise during the period of increased admission; to prevent this, additional air shall be exhausted from the chamber.

12.5.7.3 *Precautions before re-entry*

Before personnel are re-admitted to the working chamber after blasting, the recorder of the automatic monitoring system, or the quality of the atmosphere issuing from the outlet main from the working chamber, shall be checked to determine that the atmosphere has reached a fit state for entry.

12.6 BLASTING IN HOT MATERIAL

12.6.1 General

Material shall be defined as hot if its temperature is 55°C or more but less than 100°C.

If there is a possibility that the material is oxidizing or reactive, as is occasionally the case with some sulphide minerals, additional precautions shall be taken (see Clause 12.9).

12.6.2 Temperature measurement

An instrument suitable for measuring in the specified temperature range shall be used and the instrument shall be placed in the blasthole for a sufficient length of time to give a stable reading.

Blastholes that break through shall be sealed for 4 h prior to reading the temperature.

When hot material is indicated in any blasthole, the temperature of all the blastholes in the material to be blasted shall be measured within 24 h of the beginning of the shift in which charging commences.

In the particular case of mining at depth with a known temperature gradient or geothermal gradient, the following apply:

(a) Temperature measurements shall be taken where blasthole temperatures are expected to exceed 55°C as determined from the temperature gradient or geothermal gradient for the immediate locality.

(b) The temperature of development decline faces shall be determined by measurements taken in holes located within 10 m of the face once per week. The holes shall have the same length as those in the face to be blasted. A sufficient number of holes shall be selected to enable all geological rock types to be represented.

(c) The temperature in each decline face shall be compared to the expected temperature for the particular elevation and, if a variation of greater than 3°C occurs, measurements shall be made on a daily basis on that face.

(d) The nominal temperature used for any particular vertical section of a stope blast shall be the highest temperature expected in that section from the temperature gradient.

NOTE: A period of 2 h should elapse between the drilling of the hole and temperature measurement due to the cooling effect of the flushing water and air.

12.6.3 Types of explosives

12.6.3.1 *Time limits*

The following limits apply to the use of explosives for blasting in hot material:

(a) Explosives having a nitroglycerine base shall not be used.

(b) ANFO may be used without restriction in hot material, provided that the possibility of oil loss is taken into account.

NOTE: At high temperatures, ANFO made with low aromatic oils tends to have a lower oil loss than ANFO made with fuel oil.

(c) The manufacturer's recommendations for suitable temperature limits for water-gel, emulsion and other types of explosives shall be followed.

12.6.3.2 *Charging*

The time between the charging and the firing of a blast shall leave sufficient margin to assure reliable function of the initiation system and complete detonation of the explosive.

As the effect of heat on safety fuse is adverse, safety fuse shall not be used in hot material blasting.

NOTES:

1 Electric detonators to be used should preferably be fitted with polypropylene insulated lead wires as this insulation will withstand greater heat without softening.

2 Connections with detonating cord should be made not less than 300 mm from the free ends of the cord.

3 The effect of heat on signal tube is to make fuel oil penetration more rapid. The sleep time of the signal tube to be used should be sought from the manufacturer.

12.6.4 Misfires

Misfires shall be dealt with immediately they are located using the procedure described in Section 10.

NOTE: The working place should be 'mucked out' and the face examined within one working shift of the firing of that face.

12.7 HIGH TEMPERATURE BLASTING

High temperature blasting is defined as the blasting of materials at 100°C or greater. Where high temperature blasting is to be used, advice shall be sought from a specialist in this area. Such blasting shall be carried out by a specialist in this area.

When using explosives under high temperature blasting conditions, it is necessary to adopt special precautions. Hence, each shot shall be planned in detail so that it is made with deftness, speed and safety.

12.8 DEMOLITION

If explosives are to be used for demolition purposes, contact should be made with the appropriate authorities well in advance of the intended date of firing.

For demolition involving structures, or components of a structure, the requirements of AS 2601 shall be complied with.

NOTE: For guidance on demolition of structures, see Appendix K.

12.9 BLASTING IN OXIDIZING GROUND

In oxidizing or reactive ground, sheathing of ANFO explosives or other measures to inhibit exothermic reactions between the explosives and the material to be blasted may be necessary.

In the case of oxidizing or reactive ground, the explosives to be used and the charging practices to be adopted shall be developed in conjunction with explosives manufacturers, explosives consultants, or other expert authorities using the risk management process.

NOTES:

1 Reactive ground is often associated with sulphide ores, especially iron-containing sulphides.

2 Reactive ground can be encountered at ambient temperatures.

3 Oxidization is often indicated by very low groundwater pH and by rapidly increasing borehole temperature soon after drilling.

12.10 LASER HAZARDS

Attention is drawn to the possible hazards associated with higher output lasers that may be used in some mining and construction operations. While the possibility of initiation of explosives is low, the danger to the explosives operator may be more significant.

NOTE: Further guidance can be found in AS/NZS 2211 (all parts as applicable) and AS 2397.

APPENDIX A

BLAST MANAGEMENT PLAN AND RECORDS

(Normative)

A1 INTRODUCTION

All blasts shall be planned and designed to achieve the required outcome with minimum impact on the surrounding environment, below, on or above the soil or water surface. Records that detail the results of each blasting operation should be taken and maintained. This information assists in the planning and implementation of further blasts and provides documentation in case of incident or complaint.

A2 BLAST MANAGEMENT PLAN

A2.1 Purpose

The purpose of the blast management plan is as follows:

(a) Detail the objectives for the project or task.

(b) Identify risks and hazards associated with the objectives, including control and/or mitigation.

(c) Identify site-specific requirements including selection of personnel, training programs and communication systems.

(d) Introduce blast as part of the overall task in a planned manner.

(e) Control the blast process from design to initiation, evaluation and misfire treatment.

(f) Implement a review process to ensure that the objectives are met.

(g) Assure compliance with the approval/contract specifications.

(h) Assure the safety of the public, site personnel and surrounding properties.

Where required, the plan shall be submitted to a regulatory authority for authorization; otherwise the components of the plan shall be submitted to one or more competent persons, within the organization conducting the blast, responsible for such authorization.

A2.2 Contents

A blast plan, should include, but not be limited to, the following:

(a) Location of the proposed blasting.

(b) Description of the proposed blasting.

(c) Permits/licences required for the project.

(d) Identification and position of the person responsible for the project including project safety and security.

(e) Identification and position of person who has given approval to use explosives on the project.

(f) Key appointments and responsibilities.

(g) Shotfirer’s details.

(h) Details of the risk management assessment.

(i) Details of adjacent structures or services that influence the blast design.

(j) Details of reports, drawings and records consulted.

(k) Layout plan of the blast including drilling pattern and hole depths.

(l) Detonation sequence/effective charge mass per delay (MIC)/powder factor.

(m) Type of explosive to be used and quantity required.

(n) Method of initiation.

(o) Type of firing equipment and procedures.

(p) Drilling procedures.

(q) Explosive loading and charging procedures.

(r) Explosive storage and handling procedures.

(s) Security procedures for the site and the blast, including explosives.

(t) Environmental considerations for airblast overpressure, ground vibration.

NOTES:

1 Information on air blast overpressure and ground vibration is given in Appendix J.

2 Information on flyrock and fly is given in Appendix E.

(u) Details of communication systems.

(v) Warning procedures.

(w) Traffic management plan.

(x) Proposed dates and times of blasting.

(y) Details of the exclusion zone.

NOTE: See Appendix L.

(z) Method of notification to owners and occupiers of structures, and providers of services adjacent to the blast.

(aa) Influence of weather.

(bb) Loading in poor light conditions or reduced visibility.

(cc) Cessation of explosive-related activities during electrical storms.

(dd) Misfire management system.

(ee) Post blast assessment and inspection procedures.

(ff) Provision for post-blast comments.

(gg) Signature spaces for the plan author, shotfirer and person who approves the plan.

A3 BLAST RECORDS

Details of the blast should be taken and maintained, including but not limited to the following:

(a) Environmental conditions at the time of the blast.

(b) Monitoring equipment including type, serial number and location.

(c) Details of measurements recorded during the blast.

(d) Details of flyrock or fly.

(e) Details of incidents and complaints.

(f) Comment on the results of the blast.

(g) Proposed modification to the blast plan for future shots.

Provision for this information may be made on the blast plan.

A4 TUNNEL AND MINE DEVELOPMENT BLAST RECORD

Elements of safety associated with tunnel blasting, such as the possible presence of hazardous atmospheres and inrush should be recorded.

A5 DEMOLITION OF STRUCTURES

NOTE: Guidance on completing a blast plan for demolition of structures is given in Appendix K.

APPENDIX B

EQUIPMENT FOR ELECTRICAL FIRING

(Normative)

B1 GENERAL

Clause 2.5 requires that equipment used for testing and firing electric detonators shall comply with the requirements of this Appendix and that, where appropriate, compliance be verified by testing in accordance with the test methods specified herein.

The specification for circuit testers, exploders and firing cables set out in Paragraphs B4, B5, B6 and B7 apply only to equipment used to fire detonators that have no-fire currents in the range 180 mA to 250 mA.

NOTES:

1 Group 1 detonators have a bridge resistance of 0.9 Ω to 1.6 Ω.

2 The requirements for other types of equipment would normally be set by the regulatory authority.

3 For detonators other than Group 1, the specification for circuit testers, exploders and firing cables should be determined accordingly.

B2 APPROVAL OF EQUIPMENT

In general, exploders and circuit testers will require approval. Equipment shall comply with the following requirements:

(a) The equipment shall pass such tests as the regulatory authority considers necessary to establish their qualities and, in particular, their safety (see Note 1).

(b) The equipment shall comply with any construction and performance requirements specified by the regulatory authority.

(c) The equipment shall be durable, robust, functionally reliable and suitable for use in ambient temperatures normally found in Australia (−5°C to 45°C).

(d) Any enclosing case shall be constructed to prevent the ingress of dust or splashed liquids, as far as is reasonably practicable.

(e) For exploders and circuit testers, the insulation resistance between the circuit and the case shall be greater than 50 MΩ at 500 V when measured after conditioning for 24 h in an ambient temperature of maximum 20°C and relative humidity of at least 90%.

NOTES:

1 Certification to other national or international Codes or Standards may be acceptable.

2 Exploders and circuit testers are electrical instruments and should be accorded the care in handling and use appropriate to such instruments.

B3 CARE OF EQUIPMENT

All equipment shall be maintained in good and efficient condition.

B4 CIRCUIT TESTER

The circuit tester shall be a special type of ohmmeter, manufactured so that under any operating conditions it will deliver less than 50 mA when short-circuited.

NOTE: The use of a battery with an output limited to 50 mA is recommended. The scale of the instrument should be graduated to give clear readings from 0.5 Ω upward and for convenience the scale may be divided into two or more ranges.

Any adjustment or replacement of batteries in circuit testers shall be done either by the manufacturer or strictly in accordance with instructions issued by the manufacturer.

The circuit tester shall be reliable in performance and be accurate to within ±0.5 Ω or within 7% of true resistance value, whichever is the greater.

B5 EXPLODER

B5.1 Maintenance

The maintenance of exploders shall be carried out by a competent person. For mechanically operated exploders, the moving parts shall be lightly lubricated, care being taken to prevent excess oil spreading to the commutator and brushes.

NOTE: The interior of the exploders should be kept free from dust and the exterior should be clean and dry. The terminals should be kept clean.

B5.2 Routine testing

The exploder shall be tested by means of the rheostat described in Paragraph B6 or by an alternative means provided by the exploder manufacturer.

Where the rheostat method is used, the rheostat shall be constructed to the specifications of Paragraph B6, together with two detonators, and connected in series across the exploder firing terminals. Both detonators shall be shielded separately, so that one will not initiate the other, and no injury can result to any person in the vicinity. The rheostat shall be set for a rated capacity one unit less than the rated capacity of the exploder. The exploder shall be operated according to prescribed instructions. Both detonators shall fire.

B5.3 Construction

In addition to the general requirements set out in Paragraph B2, the construction of the exploder shall comply with the following:

(a) The exploder shall be provided with a protective case incorporating carrying straps or handles.

(b) The output terminals or connecting arrangements shall be designed and sized so as to allow convenient and secure attachment of firing cables of the size specified in Paragraph B7.

(c) The exploder shall be so constructed that it can only be made operable by a removable handle or key, and it shall only be possible to remove this handle or key in the ‘off’ or ‘safe’ position.

    The following types of exploders are available:

    (i) *Generator type* Generator type exploders have a dynamo, the armature of which is manually rotated through gearing from either a plunger rack-bar or a twisting handle. They are normally used for series firing.

    (ii) *Capacitor type* Capacitor-type exploders have one or more capacitors that are charged from either a battery or a dynamo having a manually rotated armature. Capacitor-type exploders are suitable for series firing, and most may be used to a limited extent for firing series-in-parallel circuits.

    Capacitor exploders are fitted with a device to indicate when sufficient electrical energy is available to fire the circuit of detonators.

    A special variant of capacitor type exploders embodies several capacitors, each of which is used to fire one circuit of detonators. Internal timing controls allow the capacitors to discharge into their detonator circuits at predetermined time intervals thus providing sequential firing.

(iii) *Sequential or sequence switch type* The sequential or sequence-switch-type exploders provide delay firing intervals of predetermined duration. A manually or mechanically rotated sequence switch directs electrical energy to fire each detonator/circuit in turn as the rotating arm passes over the appropriate contact.

B5.4 Labelling

The exploder shall be labelled as follows:

(a) *Instructions for use* A permanent label of instructions shall be secured to the exploder by screws, rivets or other permanent means.

NOTE: The instructions should be visible during use.

(b) *Removal of key* A prominent label shall be fixed to the front face of the exploder, readily seen when inserting the key with the exploder in or out of its protective case, bearing the words 'REMOVE KEY AFTER FIRING' or 'REMOVE HANDLE AFTER FIRING', as appropriate.

(c) *Capacity* The capacity, expressed in terms of the maximum number of defined detonators or the maximum series circuit resistance that can be fired by the exploder, shall be marked on the exploder.

(d) *Battery* The type of battery required.

NOTE: Leak-proof batteries are recommended.

B5.5 Electrical design features

B5.5.1 *Firing output*

The exploder shall be capable of producing an output current only with the firing mechanism in one definite firing position. With a connected resistance of $2.1(n + 1)\ \Omega$, where n is the rated capacity of the exploder for any single operation of the firing, the output current shall be as follows:

(a) For a constant output exploder ....1.4 A for 3.5 ms.

(b) For a capacitance exploder .... not less than 8 mJ/Ω.

Once a firing output has been produced, the firing controls shall be returned to the 'off' or 'safe' position or otherwise cancelled before another firing output can be produced.

B5.5.2 *Abortion of firing*

The sequence for obtaining a firing output shall be able to be abandoned at any point up to the final firing position without producing an output current.

B5.5.3 *Component malfunction*

The design of the exploder shall be such that a firing output shall not be produced through component malfunction. For the purpose of this Paragraph, 'malfunction' shall include mechanical and electrical failure of a switch, an earth fault on any part of the equipment, and an open-circuit or short-circuit occurring on any component or any part of the electrical circuit.

NOTE: It is recommended that at least two components would need to malfunction before an unintentional firing output is produced.

B5.5.4 *Generator-driven exploders*

For exploders whose output is directly provided from a generator, suitable means shall be provided to ensure that current is not put to line until the firing output required by Paragraph B5.5.1 is available.

B5.5.5 *Exploders of the capacitor-discharge type*

For exploders of the capacitor-discharge type, the following requirements apply:

(a) Where the firing circuit is made automatically, no current shall be put to line until the capacitor is adequately charged and the firing output required by Paragraph B5.5.1 is available.

(b) Where the firing circuit is made by a manually operated switch, an indication shall be given when, and only when, the capacitor is adequately charged.

(c) When the removable handle or key is removed (see Paragraph B5.3(c))—

  (i) the capacitor shall automatically be discharged over a period of not more than 3 s (see Note); and

  (ii) the firing terminals shall be short-circuited.

  NOTE: A resistor is normally used, as discharging a capacitor by means of a direct short-circuit can damage the capacitor and result in a reduction in capacity of the exploder.

(d) When there is no external circuit connected, adequate provision shall be made to discharge the exploder over a period of not more than 3 s.

  NOTE: A bleed resistance comprising two resistors of adequate rating connected in parallel across the output terminals can be used.

(e) In the ‘off’ or ‘safe’ position, any battery used in the exploder shall be electrically disconnected from the capacitor.

B6 RHEOSTAT

Where a rheostat is used for testing exploders (see Paragraph B5.2), it shall consist of a suitable variable resistance fitted with stepped contacts or a number of resistances connected to terminals. This may be calibrated in terms of a convenient number of detonators, each contact being clearly marked with the proper number of detonators represented by the contact.

For the purpose of calculating the resistance required between steps, and allowing a factor of safety, 3.2 Ω shall be considered as the resistance for each detonator in the circuit.

B7 FIRING CABLE

Firing cable for use with portable-type exploders, except sequential exploders, shall comply with AS/NZS 3191 and shall be of two-core flexible cord, thermoplastic insulated and sheathed. The cores shall be multi-stranded copper conductors having a minimum cross-sectional area and maximum resistance as follows:

(a) Heavy duty.. 2.0 mm^2, not more than 2 Ω/100 m of cable.

(b) General duty.. 1.0 mm^2, not more than 5 Ω/100 m of cable.

The cable shall be maintained in a sound condition, care being taken to avoid kinks, cuts and abrasions.

NOTE: A suitable type of heavy-duty cable is 50/0.25 mm, preferably yellow in colour.

APPENDIX C

FIRE PRECAUTIONS

(Informative)

C1 GENERAL

If a fire occurs and explosives may be at risk, personnel should be aware of the possibility of an explosion and should take suitable precautions.

The fire and explosion hazards of ammonium nitrate and ammonium nitrate mixtures are different, as the latter should be regarded as an explosive.

After extinguishing the fire, the residue should be disposed of in accordance with the requirements of the regulatory authority.

> **WARNING: THE FUMES PRODUCED BY THE BURNING OF AMMONIUM NITRATE OR EXPLOSIVES ARE TOXIC.**

C2 AMMONIUM NITRATE

Limited-area fires, even in large quantities of ammonium nitrate, can be fought with copious quantities of water. It is important that the mass be kept cool. As much ventilation as possible should be provided to the fire area, to dissipate the products of decomposition and the heat of reaction.

In massive fires, an explosion hazard exists and firefighting should be abandoned unless large volumes of water can be applied by remote control.

Water acts only as a cooling agent. Ammonium nitrate, an oxidizing material, does not need atmospheric oxygen for reaction. Consequently, fires cannot be smothered and chemical extinguishing agents are ineffective.

C3 EXPLOSIVES

When explosives are threatened by fire, they should be removed only if this can be done promptly and safely. All loaded explosive trucks and trucks containing raw materials used in the mixing of explosives may be removed from an area if this procedure can be carried out promptly and safely. If this is not possible because the involvement of explosives is imminent, the area should be evacuated in anticipation of an explosion and containment of the blaze should only be attempted with copious quantities of water if remote control means are available.

APPENDIX D

PREPARATION OF PRIMERS

(Informative)

D1 PRIMING

Typical methods of preparing primers are shown in Figure D1.

D2 METHODS

When using detonating cord with trunk and branch lines, the following recommendations should be observed:

(a) A detonating cord of sufficient strength to reliably initiate the explosive product should be selected.

(b) The cord should be cut from the roll at the top of the blasthole to leave an excess of about 0.5 m or greater protruding for later attachment of the trunkline or detonator.

(c) Connections between trunk and branches and between detonators and detonating cord should be made as shown in Appendix F.

(d) Sealing tubes or tape, or other sealing compound (or both) should be used on all joints or open ends of detonating cord where protection is required from weather or water.

(e) Whenever there is a change of direction in trunk or branch lines, the radius of bend in the cord should be not less than 75 mm.

(f) All detonating cord lines should be sufficiently taut to prevent formation of loops but sufficient slack should be left in branch lines to allow for possible subsidence of materials in the blastholes.

(g) It is also desirable to initiate the detonating cord in such a manner that two detonating paths to each blasthole are available.

When using detonators to prepare primers, the manufacturer's recommendations should be followed.

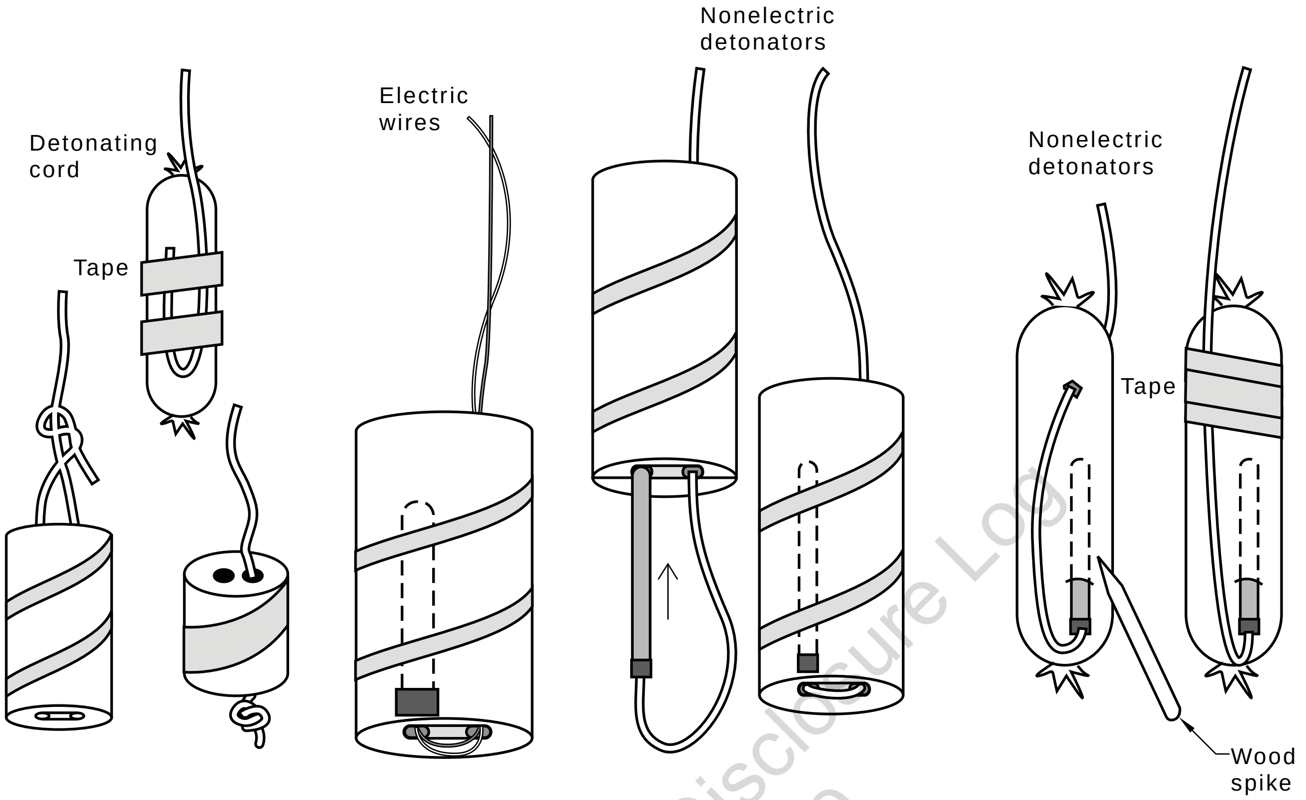


FIGURE D1 PREPARING PRIMERS

APPENDIX E

FLYROCK AND FLY

(Informative)

E1 INTRODUCTION

Because the potential for severe injury or property damage exists, precautions against flyrock and fly should be foremost in the mind of any shotfirer. The closer to persons or property that blasting is carried out, the greater should be the awareness, care and degree of protection exercised in avoiding flyrock and fly incidents.

Paragraphs E1 to E3.7 mainly address the projection of rock and not debris or other material in general. However, debris that may be on, near, or around a shot may become fly and many of the principles used in the control of flyrock can be adopted to control fly. Flyrock and fly occurs when explosive energy in the form of gas expansion energy is vented violently into the atmosphere and projects rocks and/or debris outward and away from the blast area. Fly generated as such represents a serious problem for users of explosives, who must ensure the safety of persons, equipment, and property in the area surrounding the blast.

A number of incidents have been recorded where persons have been killed or injured as a direct result of fly from blasts. An even greater number of instances report property damage and near misses.

E2 FLYROCK FORMATION

E2.1 Contributing factors

Many factors contribute to the occurrence of flyrock. These include—

(a) weak rock structure;

(b) insufficient front row blasthole burdens;

(c) stemming depth;

(d) initiation sequence;

(e) blasthole diameter;

(f) blast pattern shape; or

(g) stemming material.

These factors are considered in Paragraphs E2.2 and E2.7.

E2.2 Weak rock structure

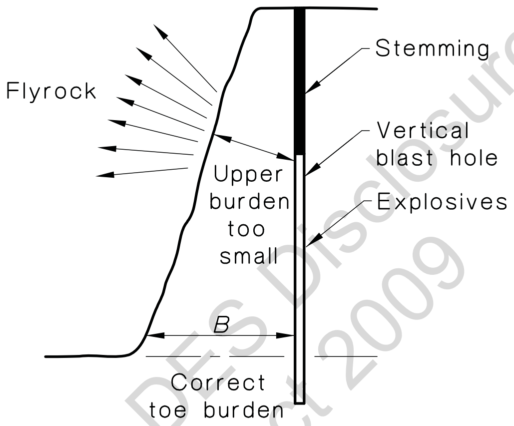
Where explosive charges intersect or are in close proximity to major geological faults or zones of weakness, the high pressure gases formed upon initiation of the explosive column seek out and preferentially jet along these paths of lower resistance, resulting in a concentration of gas expansion energy. Ideally this energy is required for rock fragmentation and heave but, in this instance, it is dissipated as noise, airblast overpressure and flyrock.

E2.3 Front row blasthole burdens

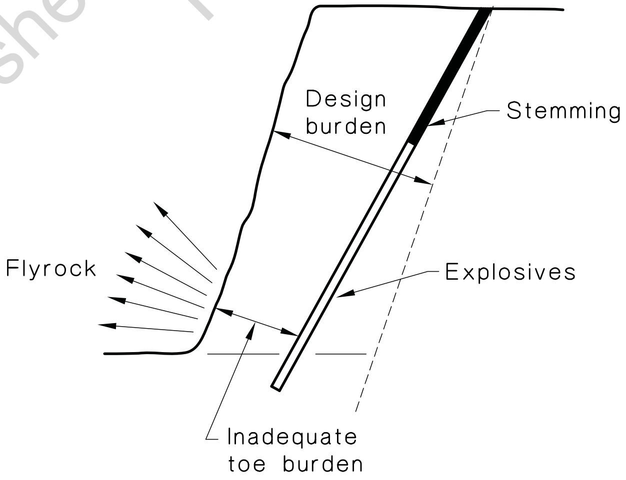
Destructive flyrock can be ejected from front row blastholes where insufficient rock burden exists between the explosive charge and the free surface. This can occur near the collar region (see Figure E1(a)) or near the toe where the face has been undercut or where excessive blasthole deviation has occurred (see Figure E1(b)).

E2.4 Stemming depth

The stemming region of a blast block usually incorporates a zone of rock that has been weakened by surface weathering, or previously fractured due to subgrade blasting from the bench above. In this region, blast gases easily jet into and propagate cracks to the free surface. As the stemming depth decreases (see Figure E2), a larger proportion of blast gases are available for premature ejection resulting in an increase of observable flyrock. As a conservative guideline, the depth of stemming should be equal to or greater than the burden.



(a) Inadequate burden in the collar region



(b) Inadequate toe burden

FIGURE E1 FRONT ROW BLASTHOLE BURDENS

E2.5 Initiation sequence

In rock breakage, optimum fragmentation and muckpile looseness is achieved when the principal rock movement is forward. This progressive relief of burden is achieved by peeling the blastholes away from the blast block with the use of inter-row delays. If these inter-row delays are not used or are not adequate for a given blast design, then each explosive charge will crater to the upper horizontal plane as this offers the least path of resistance for the escaping high pressure blasthole gases. These gases will create flyrock as shown in Figure E2. When blastholes are initiated out of sequence (e.g., back row before front row), a similar effect occurs, with consequential flyrock.

E2.6 Blasthole diameter

When a blasthole is increased in diameter, the linear charge-weight of fully coupled explosives increases by the square of the ratio of the diameters. This means that when changing from a 100 mm to a 200 mm diameter blasthole, the explosive weight per metre has increased by a factor of four. If a change in explosive charge distribution (particularly collar height) is not made when increasing the blasthole diameter, the increase in explosive energy in the presence of major geological faults, inadequate burdens or poor stemming may produce catastrophic flyrock.

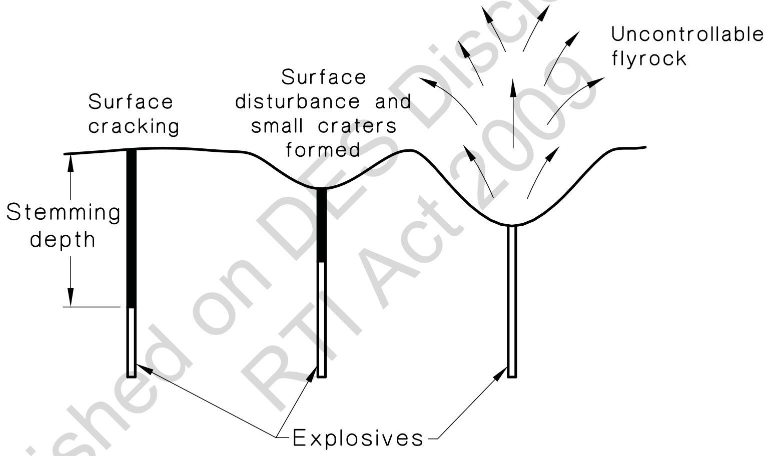


FIGURE E2 FLYROCK GENERATION DUE TO STEMMING DEPTH REDUCTION

E2.7 Stemming material

Poor stemming or a total lack of stemming will result in flyrock. Stemming acts as a plug to trap blast-generated gases in the blasthole where they will do useful work in fragmenting and heaving the rock mass. If this stemming is inefficient or is absent, blast gases will stream up the blasthole along the path of least resistance resulting in ejection of the collar rock as harmful flyrock. Should the stemming column contain individual rocks that are of disproportionate size to the blasthole diameter, it is possible for these rocks to be shot in missile fashion over long distances and consequently constitute a potential flyrock hazard.

E3 FLYROCK CONTROL

E3.1 General

The rapidly expanding gases resulting from the initiation of explosives create high pressures, which have to be relieved in a controlled manner. These high-pressure gases will tend to expand in directions that offer the least resistance, such as free faces and areas of weak rock structure. By correctly structuring blast designs and by skilfully and carefully drilling and loading the blast, flyrock formation can be controlled to acceptable levels.

When drilling and shooting in broken or weathered rock, difficulties will be experienced. Drilling will be difficult, as the air will be distributed throughout the cracks and fissures preventing sufficient pressure to build up in the blasthole for cuttings to be efficiently flushed out. Shotfirers should always confer with the driller or examine drill logs before loading any shot.

Control of flyrock can be difficult where the free face is horizontal, such as the initial blastholes in a pit, trench, or shallow road cutting blasts (see Figure E3).

The probability of flyrock can be reduced by drilling through overburden and using it as cover, rather than removing it before drilling and blasting.

Danger from the upward throw of rock should be controlled by such means as blasting mats (plus backfill cover if necessary) or by ensuring that adequate distances exist to locations requiring protection from flyrock.

A good starting point is to ensure that stemming height is either—

(a) equal to or greater than the burden; or

(b) 25 times the blasthole diameter.

This may be varied once sufficient site experience is gained.

Where vertical free faces exist, such as in a quarry, rock throw will be substantially horizontal away from the free face (see Figure E4).

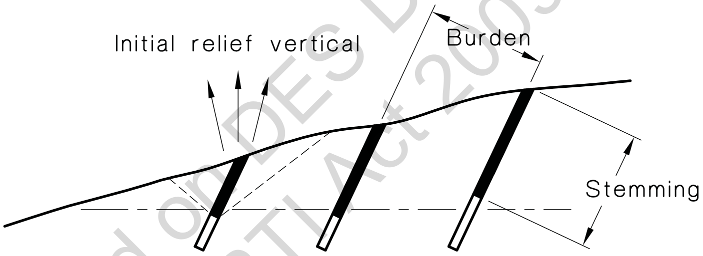


FIGURE E3 HORIZONTAL FREE FACE

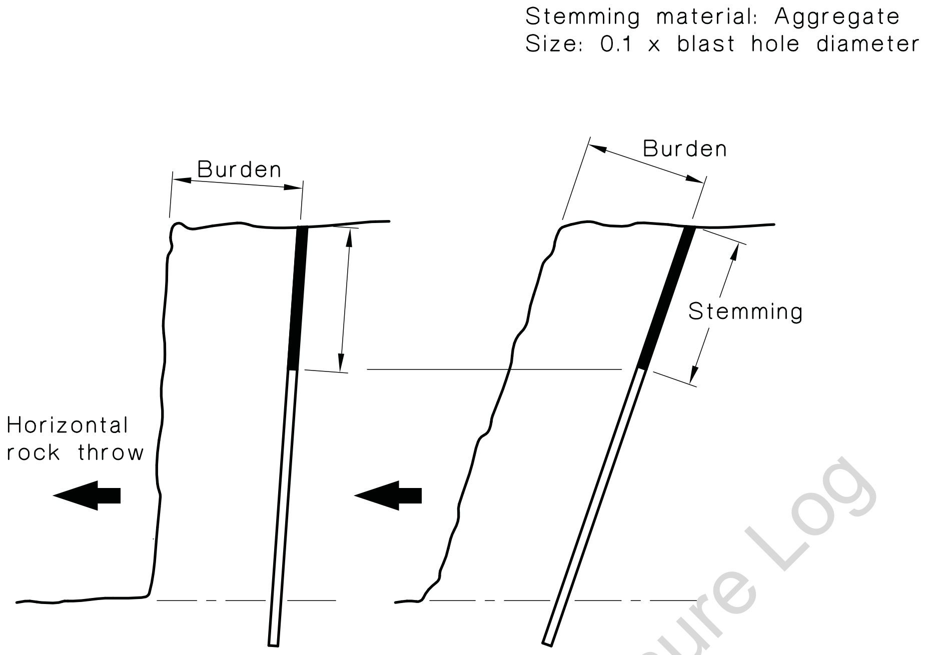


FIGURE E4 VERTICAL OR NEAR VERTICAL FREE FACE

If the free face is underburdened or contains areas of weak rock structure, flyrock danger will be increased (see Figure E5).

Concentrated charges cause problems due to loose poured explosives filling enlarged sections of blasthole, which tend to occur in areas of weak rock structure.

When loading a blasthole in broken rock, a shotfirer should be aware of the quantity of explosives being placed in the blasthole, especially when using ANFO or other bulk explosives. These types of explosives readily fill any voids and cracks, thus allowing much larger quantities in the blasthole with the same depth of stemming. This can lead to destructive flyrock and excessive airblast overpressure. Packaged explosives are recommended when this problem is encountered.

In many cases, when blasting in broken rock, the shot will be rather ineffective as the gases formed from the initiated explosives will dissipate into the cracks and voids. In all blasting, adequate experience and local knowledge should be used.

E3.2 Examination of blast site and surveying of blast faces and blastholes

The area surrounding the blast site should be inspected to determine distances to protected works, e.g., residences, roads, public places, dangerous goods storage, and due consideration should be taken in determining the degree of protection necessary. Previous excavations can give significant information about the rock structure.

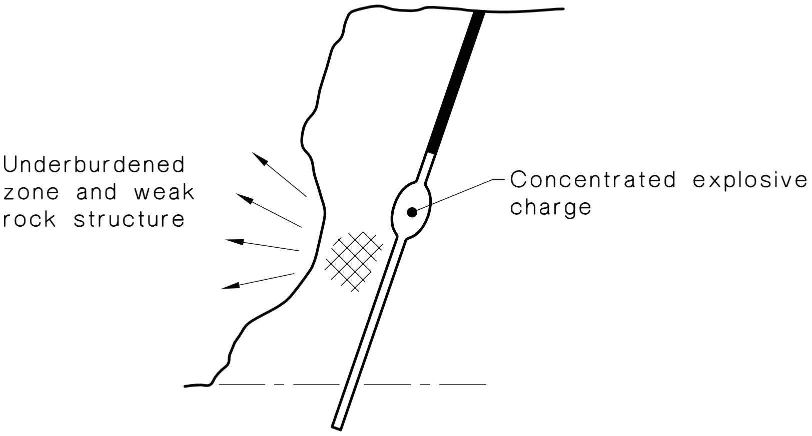


FIGURE E5 UNDERBURDENED OR WEAKENED FREE FACE

It is important that blast faces be accurately surveyed prior to marking out blastholes and before loading them with explosives. This is necessary to control flyrock and to comply with regulatory authority blast vibration limits.

There are a number of methods available for face surveying and for relating the actual blasthole drilled to the face. They vary from basic 'low-tech' methods to the latest electronic devices, but few, if any, are the complete answer. All methods have shortcomings and varying amounts of interpretation by the shotfirer are required to overcome practical problems such as the face not being fully exposed and lack of clear definition of toe and brow location.

All faces should be carefully inspected by standing in front of the face. This visual examination must be supplemented by an accurate survey to prevent problems such as excessive airblast overpressure and flyrock from underburdening, or excessive ground vibration and poor fragmentation from overburdening. Blastholes may be inclined and positioned so that they have equal burden over their total length (see Figure E6).

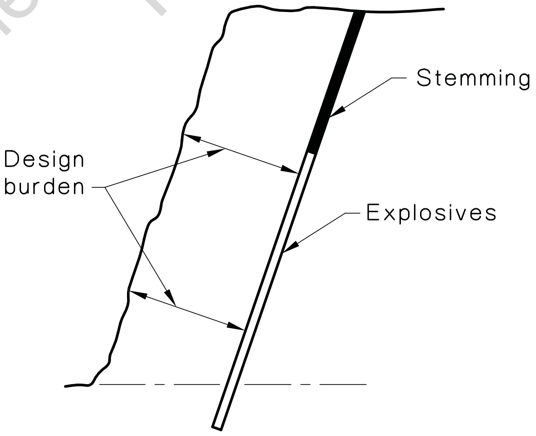


FIGURE E6 DESIGN BURDEN ATTAINED WITH THE USE OF ANGLED BLASTHOLES

The task of positioning and inclining blastholes to suit a particular face geometry can be reviewed for each front row blasthole drilled when the preceding blasted ground has been cleaned out. This represents the optimum situation and should be encouraged whenever possible.

NOTE: Large surface mining operations, which have a continuous drilling, blasting and loading cycle, in which material broken by a previous blast remains lying against the face when the next blast is fired, should use an alternative technique. In this case, the collar distance, as measured from observable back cracking from the previous blast and the blasthole inclination, should be determined following a detailed evaluation of blast records.

E3.3 Charge configuration and loading procedure

The amount and location of charge within a blasthole has the most significant effect upon the generation of flyrock. A number of factors including prominent geological structure, bench face geometry and rock strength need to be considered when evaluating the charge to be placed into a blasthole. Usually, the upper sections of front row vertical blastholes warrant less charge than subsequent rows to account for bench face irregularities and reduced burdens.

When prominent geological structures or lower strength rocks are encountered as bands either intersecting or closely located to the blasthole, deck charging or light loading techniques should be used to reduce the concentration of charge located directly adjacent to these planes of weakness.

The correct charge weight should be employed in the blasthole. When using ANFO or any other free-running explosive, pour measured quantities of the explosives into the blasthole and monitor the build-up of the explosive column by tape measure or wooden pole. This is to avoid overcharging which may result from fissures or chambers in the rock.

When planning and loading a blast, the amount of explosives used should be checked by dividing the weight of explosives used by the solid volume of material to be blasted. This ratio is called the loading (or powder) factor, and is commonly expressed as kilograms of explosives per cubic metre (solid) of material blasted. Secondary blasting (if permitted) requires a very low loading (or powder) factor, and special care should be taken to avoid overcharging when carrying out secondary blasting.

It is emphasized that all blasting personnel be adequately trained and supervised and that adequate blast charging supervision is required to ensure that loading and initiating procedures minimize the possibility of harmful ejection of flyrock during blasting operations.

E3.4 Stemming medium

Stemming is required to trap blast gases in the blasthole so that they will be utilized in effective heaving and fragmenting of the rock mass. Poor stemming or a total lack of it will result in flyrock. Visual observations and photographic records have shown that blastholes stemmed with fine drill cuttings usually show a pronounced degree of rifling and flyrock. Odd sized or rounded rocks in the blasthole can also become projectiles in the same manner.

An alternative stemming material that overcomes the problems associated with fine drill cuttings is crushed angular rock. This stemming material has many desirable features including—

(a) the ability to interlock together;

(b) the ability to wedge against the side of the blasthole wall thus providing increased resistance to premature ejection; and

(c) the ability to displace rather than absorb water in wet blastholes thus maintaining its inherent frictional properties.

For effective distribution, the size of crushed angular rock should be related to the blasthole diameter as shown in Table E1. In operations where severe flyrock restrictions apply, some form of protective cover (see Paragraph E3.7) should be considered.

TABLE E1

CRUSHED ROCK SIZING FOR VARIOUS BLASTHOLE DIAMETERS

Blasthole diameter mm	Crushed rock sizing mm
50–130	6–13
130–200	13–19

E3.5 Initiation

Adequate allowance for inter-hole or inter-row delay to enable progressive relief of burden to occur throughout a blast is a key factor in controlling flyrock ejection. The specific time interval is dependent upon the delay system (down the blasthole or on the surface), rock strength, stemming depth and explosive type.

The delay sequence should be arranged to encourage rock throwaway from locations requiring protection.

In sensitive areas (e.g., urban quarries) where most blasting utilizes less than 100 mm diameter blastholes, the use of detonating cord downlines to initiate the explosive column should be minimized as these may create a chimney effect through the stemming thus promoting premature escape of blast gases to the atmosphere. Detonating cord surface lines should not be used in sensitive areas.

E3.6 Blast pattern shape and alignment

The blast design is determined by the type of rock, the degree of fragmentation required, special anomalies or restrictions at the blast site and what result is to be achieved. Deep blasts, that is, greater than five rows for large blasthole diameters and greater than three rows for small blasthole diameters, may exhibit flyrock from the back rows. Experience has shown that the ideal case is to design blast patterns with length to depth dimensions in the ratio of 3:4 if flyrock is to be avoided.

Where major items of stationary equipment (e.g., crushers, pumping stations) are included in the pit design, it may be an advantage to orientate the bench faces so that the principal rock movement is not directly towards this equipment.

E3.7 Protective cover

Where any doubt exists, or where the blast situation demands added precautions, sufficient cover should be placed on the blast to prevent any possibility of resulting flyrock. Examples of where additional cover might be necessary are shallow blasting, proximity to protected works, or where blasting is carried out underneath powerlines or adjacent to buildings, roadways, railways, or other structures.

Common forms of protective cover include blasting mats, conveyor belting, truck tyres and steel plate but, due to their bulk, these are limited to small blasts. A technique involving the firing of a blast directly into a previously shot blast (buffer blasting) can be used to reduce any potential flyrock generated from the vertical free face. However, this technique constrains overall rock movement and may enhance flyrock due to cratering charges. Its effectiveness is limited to rocks that exhibit a high degree of natural fracturing. In situations where misfired charges are to be refired and excessive flyrock is anticipated, it may be necessary to backfill or cover the charge with broken rock to minimize the flyrock problem.

The following advice is particularly applicable to small scale blasting operations.

When backfilling is used to cover charged blastholes this should be sorted material without stones. The cover should be placed with care to avoid damage to connecting wires or detonating cord trunklines and should be to a minimum depth which would eliminate flyrock. Strips of conveyor belting laid over the leadwires will protect them from damage when backfilling.

If using blasting mats to provide cover, the following precautions should be observed:

(a) A layer of sand or sandbags should cover the rock, at least in the area of the blasthole collar, to protect the mat from being damaged.

(b) Only the number of blastholes that can be adequately covered by blasting mats should be loaded and fired at one time. Mats should be anchored where practicable.

(c) Rock or debris should not be placed on top of the mats, as these may become missiles.

(d) If firing more than one blasthole in sequence, only short (i.e., millisecond type) delay detonators should be used. Long delays (due to half-second delay detonators or safety fuse firing) may lift the mats off the remaining unfired blastholes.

(e) Mats of wire rope or steel rings should not be used in the vicinity of overhead power lines.

(f) Care must be taken when laying mats so that connecting wires or detonating cord trunklines will not be damaged.

E4 FLY FORMATION

In addition to the factors identified in Paragraph E2, fly can be generated from the many and varied blasting operations other than in rock. These include but are not limited to the following:

(a) Failure to test or research the material(s) to be blasted;

(b) Brittle nature of the material(s) being blasted, e.g., wood, steel, slag, etc.;

(c) The powder factor being used is too great;

(d) The MIC is too great;

(e) Insufficient covering or protection on or around the charges; and

(f) Materials used as a protective covering containing objects that may become fly themselves.

APPENDIX F

FIRING CIRCUIT CONNECTIONS

(Informative)

F1 ELECTRIC FIRING

F1.1 Series connection

For series connection firing of explosives, the wires are connected as indicated in Figure F1. A minimum current of 2 A should be provided for a series connection.

F1.2 Parallel connection

A parallel connection is one in which the electric detonators are connected to two common points, and calls for a higher total amperage requirement than a series connection for more than one detonator. A minimum of 0.75 A should be allowed for each detonator unless otherwise advised by the detonator manufacturer. A firing machine specifically designed for parallel firing shall be used and detonators should be tested individually for continuity. Typical circuits are given in Figure F2(a) and (b).

The use of voltages exceeding 210 V in parallel circuits may result in 'pinhole' failures in electric delay detonators due to the current arcing across from the fusehead to the detonator tube and burning a pinhole in the tube. Detonators that have been vented in this manner do not operate under designed pressure conditions, and may therefore fire erratically or misfire due to the delay element being disrupted.

Arcing, with consequent pinholing, may be controlled by ensuring that the current to the firing circuit is broken shortly after the fuseheads have fired and before arcing has commenced by—

(a) using a special firing switch incorporating a rapid 'make and break' switch mechanism;

(b) including a 50 ms delay (No. 2 short delay) detonator in the circuit and attaching it firmly to a bus wire or firing lead so that it will break the circuit in approximately 50 ms; or

(c) connecting a shunt of heavy gauge wire across the end of the firing cable.

The value of the resistance should be such as to prevent the voltage on the last detonator to fire rising above 50 V. A reverse parallel hook-up is helpful in preventing pinhole failures (see Figure F2(c)).

F1.3 Series-in-parallel connection

A series-in-parallel connection consists of a number of series circuits connected in parallel. A minimum current of 2 A should be provided for each series. The number of series that can be used is controlled by the amperage available and the number of detonators in a single series by voltage. Each series circuit should be tested in accordance with Paragraph F1.5 before being connected to parallel wires. Figure F3 illustrates a typical circuit.

F1.4 Parallel-in-series connection

In a parallel-in-series connection circuit, the detonators are connected in parallel in a number of groups and the groups connected in series. The current to be provided for this type of circuit is determined by the requirements of the primary connections. Figure F4 illustrates a typical circuit.

F1.5 Connection and testing of electrical firing circuits

When electric detonators are to be initiated through an exploder the following circuitry checks should be observed:

(a) When a series circuit is used, like-coloured wires should be joined together for ease of checking.

(b) Where clamp-type mechanical connectors are used for joining detonator lead wires, or similar connections, the insulation should not be removed and bared ends should be cut off. For the joining of the ends of all wires and cables where clamp-type mechanical connectors are not used, the insulation should be removed for a maximum length of 50 mm and the wires should then be made clean and bright for a minimum length of 25 mm. The ends to be joined should be twisted together so as to have positive metal contact.

(c) Grease-filled mechanical clamp type connectors should be used in wet conditions and with water-based explosives.

(d) If the cable and joints appear to be properly connected but overall lack of electrical continuity is still evident, each detonator should be checked for fault by connecting it individually to the cable and testing from the firing position with the circuit tester. In the case of large rounds, the circuit should be divided into halves, each half being connected to the cable and the faulty half again divided successively until the faulty detonator is identified. A similar procedure should be carried out when checking for current leakage.

(e) As well as the detonator circuits, firing cables and connecting wire should be tested for the following:

    (i) *Short-circuit* A short-circuit is indicated when a resistance reading is obtained on a circuit tester when one end of the cable is connected to the meter and the other end has both conductors separated.

    (ii) *Open-circuit* An open circuit is indicated when the meter registers an infinite resistance or a resistance substantially higher than the resistance of the cable when the open ends of a cable, at the end remote from the meter, are connected.

    (iii) *Current leakage* Current leakage is the loss of part of the firing current and is due to damaged (or inadequate) insulation in lead wires or poorly insulated connections. If the resistance of the circuit through the earth is less than the resistance of the firing circuit, current will flow through the earth in preference to the firing circuit. This can lead to misfires, as some detonators may not receive sufficient electrical energy for initiation. It is most common in moist or wet conditions or in highly mineralized ground. Current leakage can be minimized by ensuring that—

        (A) blastholes are thoroughly cleaned out before charging commences;

        (B) lead wires are not kinked; and

        (C) connections are insulated or kept clear of the ground.

    A special earth leakage tester should be used in blasts where current leakage is suspected.

(f) If the testing of the cables and circuits has been carried out satisfactorily, the ends of the cable may be connected to the exploding device.

F2 DETONATING CORD

Methods of connecting detonating cord to branch and trunklines are shown in Figures F5 to F8 and of connecting a detonator to a trunkline in Figure F9.

F3 SIGNAL TUBE

Methods of connecting branch and trunklines with signal tube and combinations of signal tube and detonating cord are shown in Figures F10 to F15.

The manufacturer's recommendations concerning the application of the various connecting devices and detonating cord charge weights should be carefully followed.

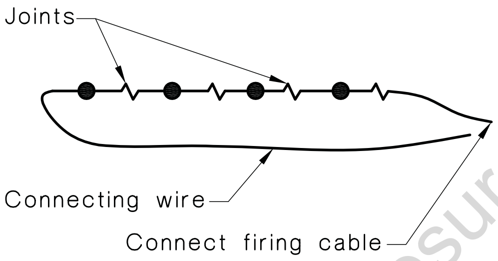
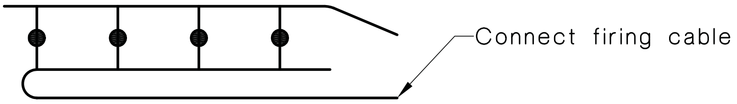


FIGURE F1 SIMPLE SERIES CIRCUIT

(a) Simple parallel circuit

(b) Alternative simple parallel circuit



(c) Reverse parallel circuit

NOTE: The resistance of each parallel series should be balanced to avoid misfires.

FIGURE F2 PARALLEL CIRCUITS

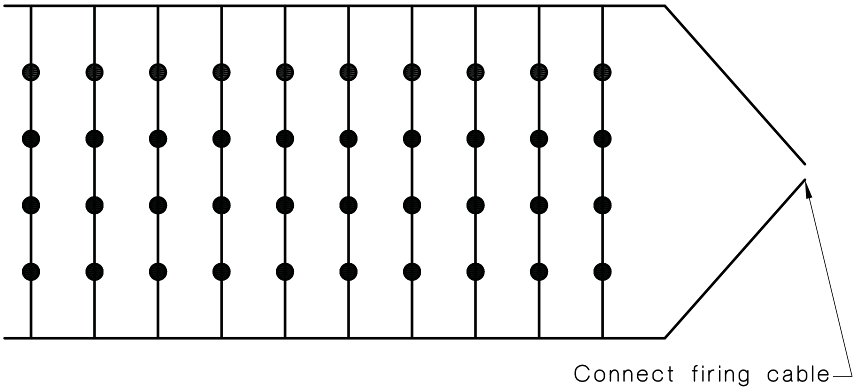


FIGURE F3 SERIES-IN-PARALLEL CIRCUIT

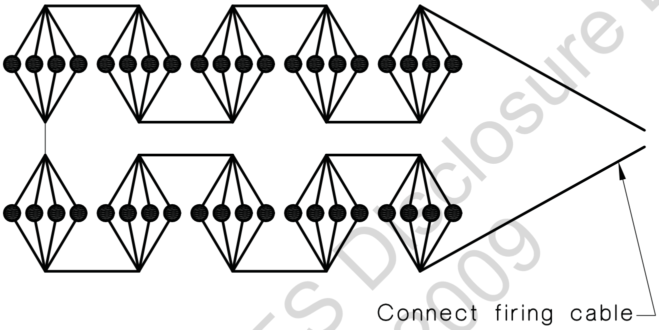


FIGURE F4 PARALLEL-IN-SERIES CIRCUIT

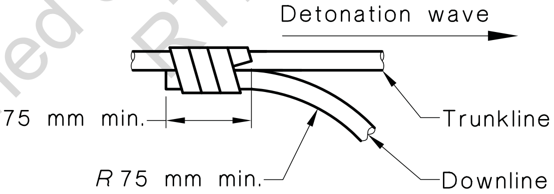
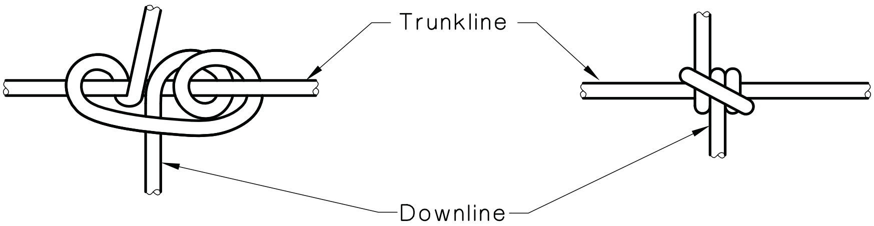
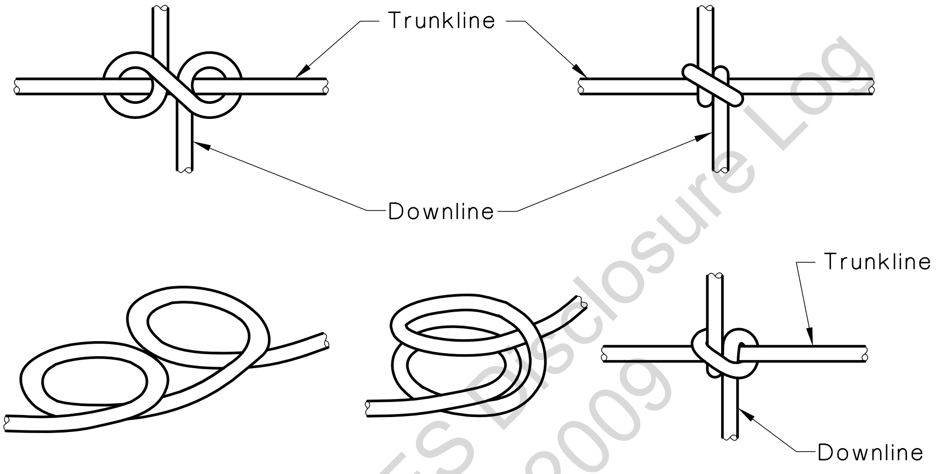


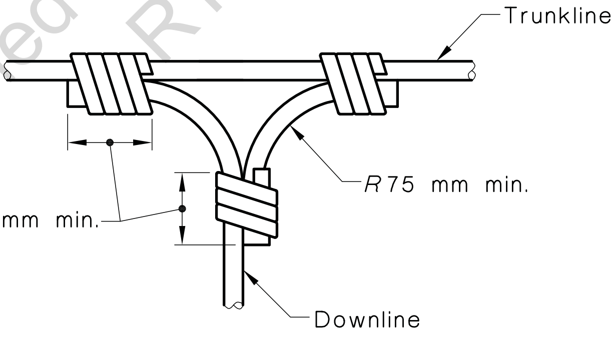
FIGURE F5 TRUNKLINE TO DOWNLINE CONNECTION FROM DETONATING CORD (INITIATION FROM ONE DIRECTION ONLY)



(a) Double wrap clove hitch



(b) Clove hitch



(c) Taped connection

FIGURE F6 DOWNLINE TO TRUNKLINE CONNECTION FOR DETONATING CORD (INITIATION FROM EITHER DIRECTION)

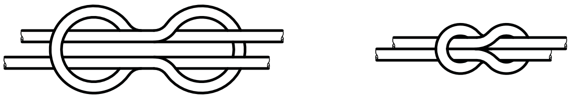


FIGURE F7 TRUNKLINE OR OTHER CORD-TO-CORD EXTENSION

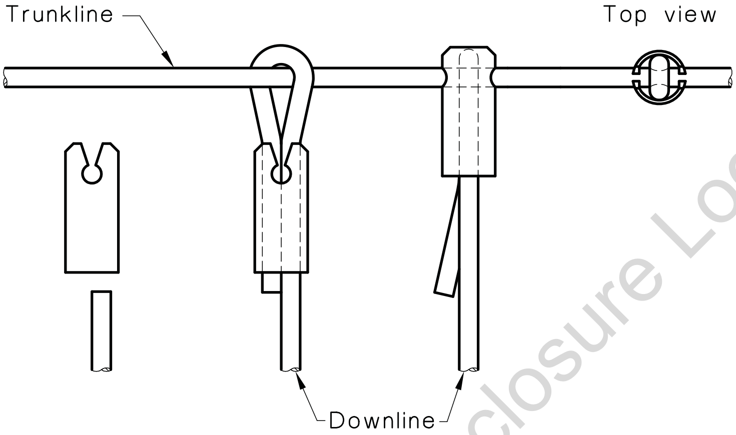


FIGURE F8 CLIP CONNECTIONS

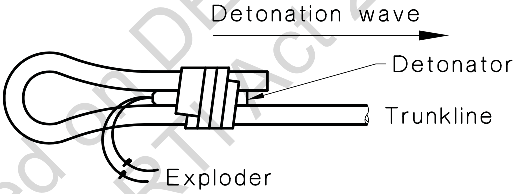
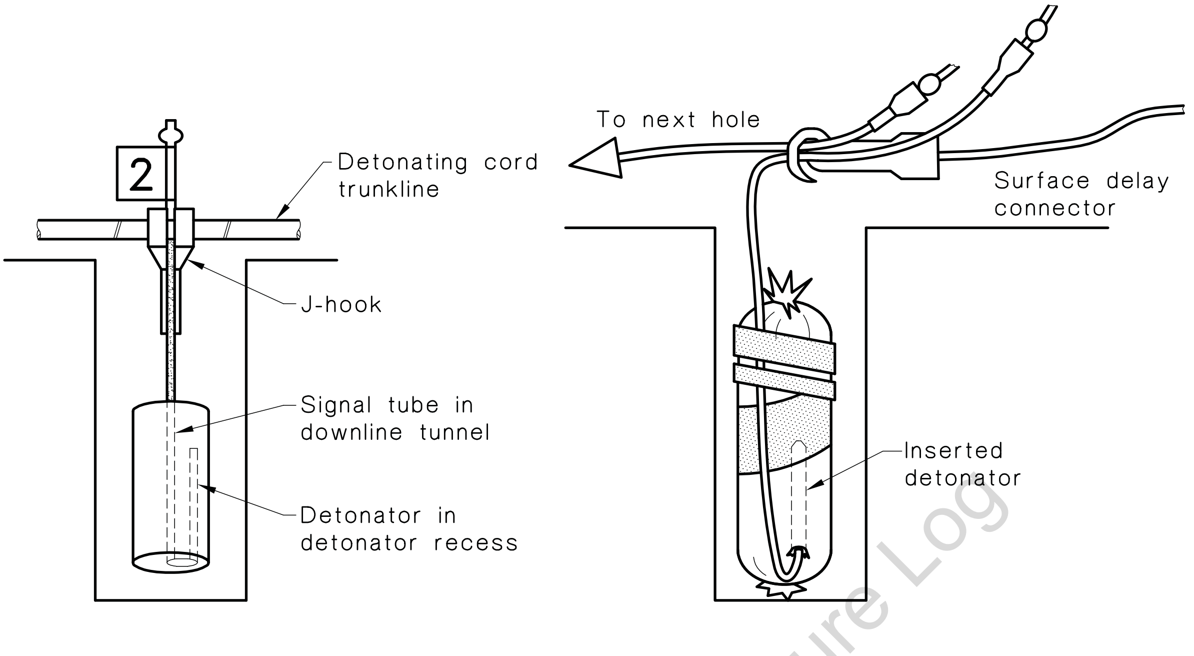


FIGURE F9 CONNECTION OF DETONATOR TO TRUNKLINE



(a) Cast primer

(b) Packaged explosive primer

FIGURE F10 REVERSE PRIMING WITH IN-HOLE DETONATORS

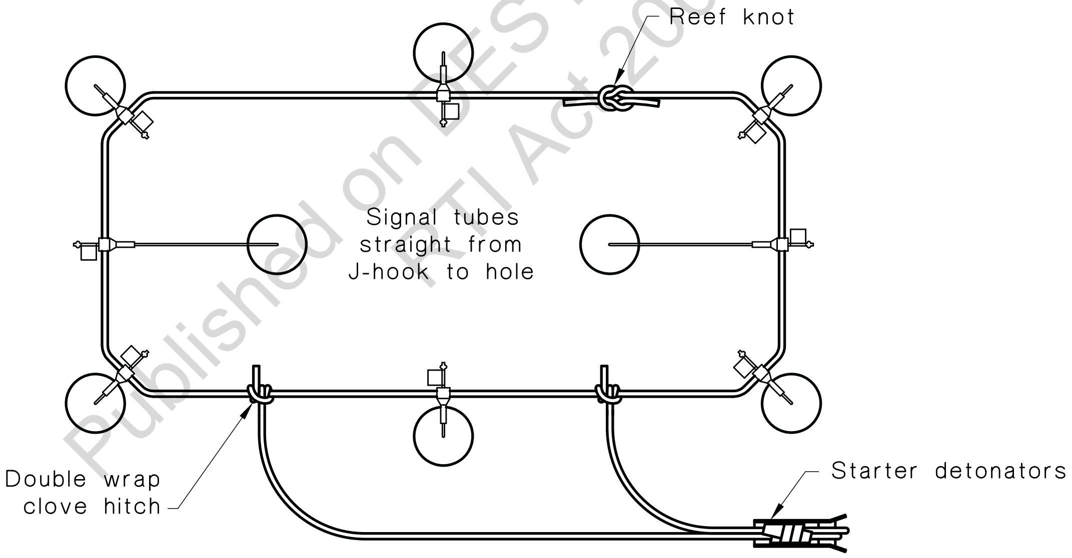
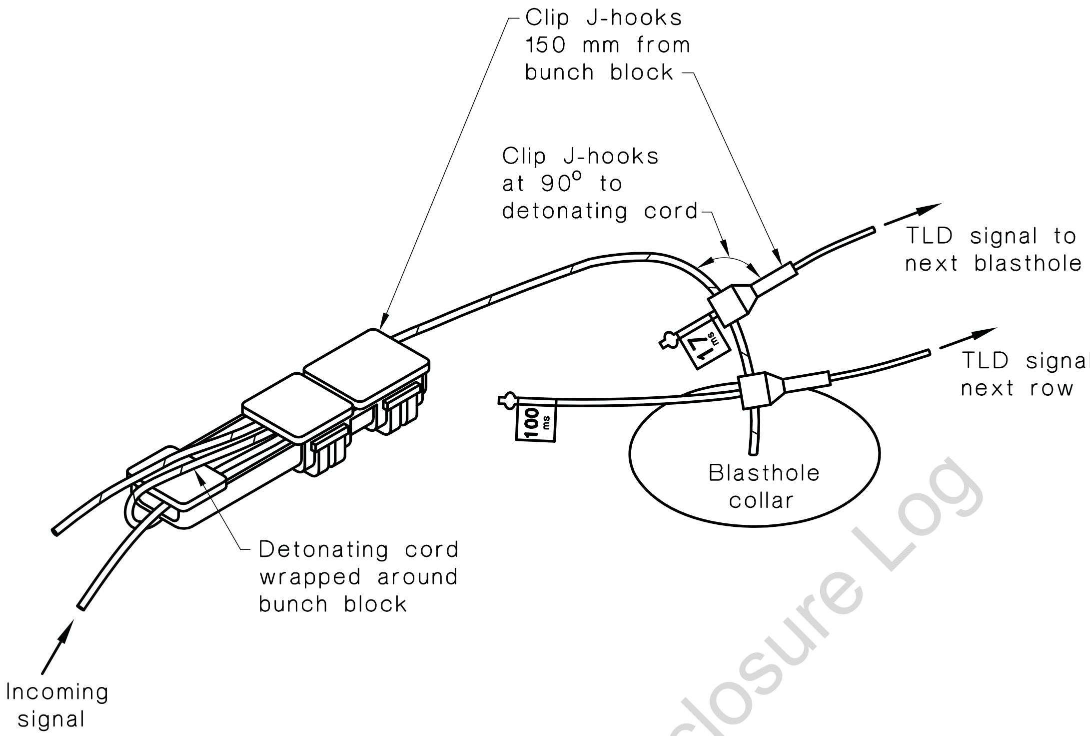


FIGURE F11 HOOK-UP—DETONATING CORD TRUNKLINES

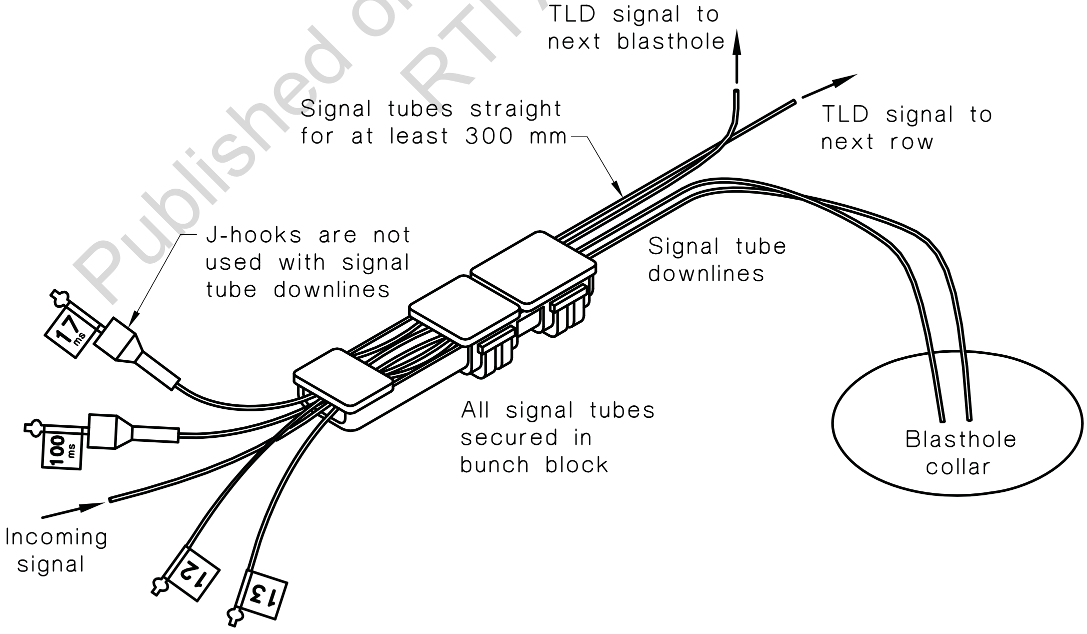


NOTES:

1 The incoming signal initiates a delay detonator held inside the bunch block.

2 All bunch blocks should be checked and covered.

FIGURE F12 TRUNKLINE DELAY HOOK-UP—DETONATING CORD DOWNLINES



NOTE: All bunch blocks should be checked and covered.

FIGURE F13 TRUNKLINE DELAY HOOK-UP—SIGNAL TUBE DOWNLINES

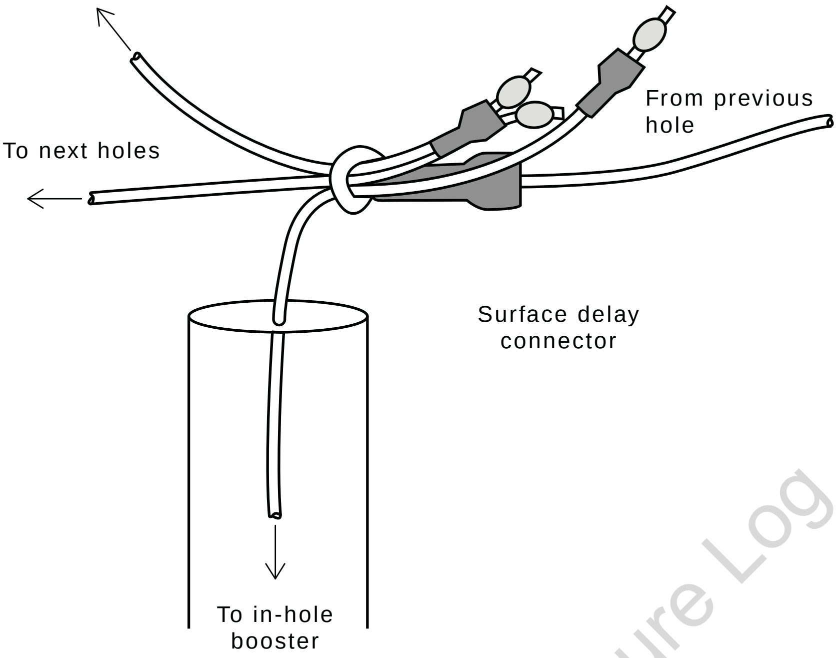


FIGURE F14 SURFACE DELAY HOOK-UP—SIGNAL TUBE DOWNLINES

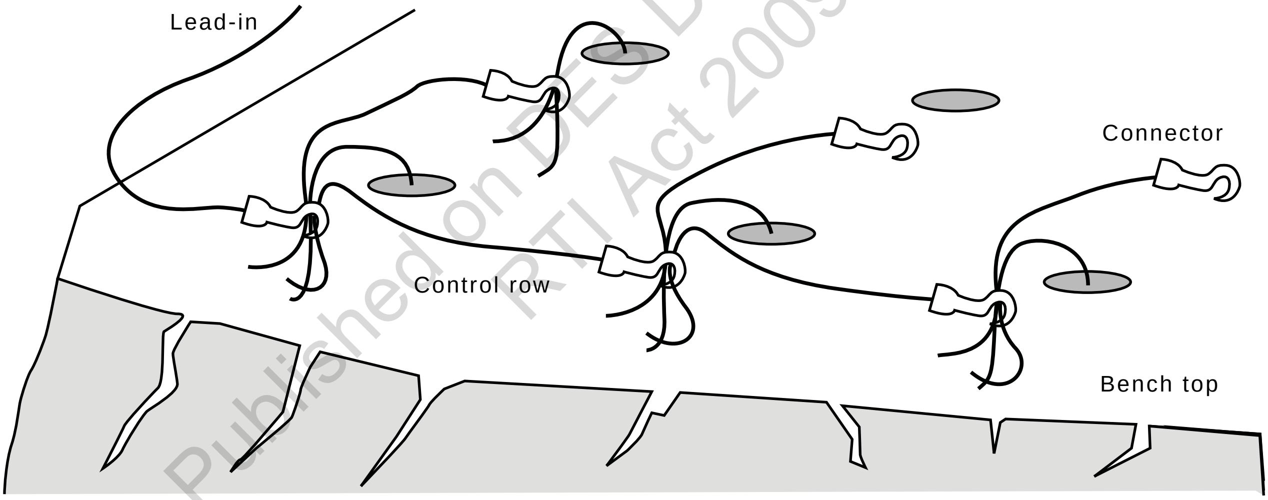


FIGURE F15 BLAST HOOK-UP—SIGNAL TUBE TRUNKLINES AND DOWNLINES

APPENDIX G

DETERIORATION OF EXPLOSIVES

(Informative)

G1 GENERAL

Explosives may become defective owing to various causes including poor storage conditions, ageing and extreme weather conditions. This Appendix sets out the more common visible signs in terms of the various types of explosives available.

G2 WATER-GEL EXPLOSIVES

Water-gel explosives are gelled, saturated aqueous solutions usually containing suspended solids and consisting of water, oxidizing salts, fuel components, and various sensitizers.

Water-gels deteriorate if the gel matrix breaks down. In these cases, the composition becomes no longer gel-like or uniform in consistency. Also the ingredients separate into readily identifiable layers, large crystals grow and the suspended solids settle down.

When water-gels deteriorate they generally become less sensitive and may not detonate. Consequently they should be destroyed as recommended by the manufacturer. If it is intended to destroy such explosives by burning, because some water-gels are difficult to ignite, a generous supply of kindling or the use of fuel oil or kerosene may be required (see also Appendix H).

G3 EMULSION EXPLOSIVES

Emulsion explosives consist of a saturated aqueous solution of oxidizing salts that are finely dispersed through a continuous oil phase. They may contain additional suspended solids and various sensitizers.

Emulsion explosives deteriorate when the emulsion structure breaks down. This may be due to a separation of the oil and aqueous phases or due to crystallization of the aqueous phase. As crystallization proceeds the explosive will lose its pliable characteristics.

As emulsions deteriorate they generally become less sensitive and may not detonate. Consequently they should be destroyed as recommended by the manufacturer. If it is intended to destroy emulsions by burning, it should be noted that some emulsions are difficult to ignite (see also Appendix H).

G4 NITROGLYCERINE/NITROGLYCOL-BASED EXPLOSIVE

The visible signs of deterioration of nitroglycerine/nitroglycol-based explosives are as follows:

(a) *Exudation* Exudation is the separation of nitroglycerine or other nitrobody from the explosive as an oily liquid, which may be retained inside or appear on the outside of the wrapper. Free nitroglycerine is sensitive to friction and percussion, and exuding explosives may thus cause premature explosions.

(b) *Moisture absorption* Moisture absorption is caused by inorganic salts, such as ammonium nitrate, in the explosive picking up water from the air. Moisture absorption usually appears initially at the ends of the plugs and extends progressively towards the centre. The liquid present is water containing dissolved salts and sometimes colouring matter.

Moisture reduces the sensitivity to detonation with consequent risk of unexploded explosives being left in blastholes. Resealing of liners of opened explosives cases or cartons will reduce deterioration from this cause.

(c) *Recrystallization* Recrystallization occurs where soluble salts, such as nitrates, have been dissolved out of the explosive by water, either absorbed or derived from some other source, and the solutions formed have dried out. This drying-out occurs normally outside the wrappers and most commonly at the ends, resulting in crystalline deposits of soluble salts.

Recrystallization involves loss of oxygen-supplying salts by the explosive mixture. Its efficiency is thereby impaired and this may result in incomplete detonation.

Recrystallization can also result in liquid nitroglycerine being trapped between the sharp crystals and it is possible for it to detonate if disturbed. For this reason it is recommended that explosives in this condition be destroyed. If it is necessary to move explosives in this condition, they should be handled carefully, without breaking up the crystallized mass.

G5 DETONATORS

Detonators can deteriorate, either from age or improper storage, so that they are unfit for use. Such detonators may be very dangerous to handle, and it is recommended that they not be disturbed until they have been inspected by the manufacturer's representative or the regulatory authority.

Detonators should be destroyed if they have ever been underwater, for example during flood, regardless of whether or not they have been subsequently dried out. In some cases, the shells that have been wet and then dried will show signs of corrosion. Many detonators contain lead azide, which is highly sensitive. In a copper shell detonator where corrosion has occurred, a reaction with lead azide can occur forming cupric azide, which is extremely sensitive and unstable.

APPENDIX H

DESTRUCTION OF EXPLOSIVES (OTHER THAN DETONATORS) BY BURNING

(Informative)

WARNINGS:

1 **BURNING EXPLOSIVES MAY EXPLODE.**

2 **THE FUMES PRODUCED BY THE BURNING OF EXPLOSIVES ARE TOXIC.**

3 **BURNING OF EXPLOSIVES SHOULD NOT BE ATTEMPTED IF SERIOUS EXUDATION OF NITROGLYCERINE IS APPARENT.**

4 **BREAKING UP OF LUMPED CARTRIDGES OF DETERIORATED EXPLOSIVES SHOULD NOT BE ATTEMPTED PRIOR TO BURNING.**

H1 METHOD

H1.1 Procedure for cartridged explosives and cast boosters

In addition to the requirements specified in Section 11, the following steps are suggested as a procedure for burning cartridged explosives and/or cast boosters:

(a) Determine the size of the exclusion zone and at what point of time it needs to be established (see Notes 1 and 2).

(b) Select and clear an area that will minimize the spread of fire. Additional precautions may be necessary.

(c) Lay out the required number of ‘trails’ of sawdust or wood shavings adequate to create a bed for the quantity of explosives to be burned, approximately 200 mm wider than the length of the longest cartridge, and 25 mm deep, upon which the explosive will be laid. The trails should be aligned with the wind direction (see Notes 3 and 4).

A maximum of four individual trails may be laid side-by-side (not end to end). They should be a minimum of 600 m apart.

(d) Thoroughly check that all cartridges are free of detonators (see Note 5).

(e) Place the cartridges on the trail making sure—

  (i) there is at least 1 m of the trail left without any explosives at the downwind end;

  (ii) the cartridges are parallel to each other (not end to end in a line) along the middle of the trail;

  (iii) the cartridges are not touching (a good rule of thumb is to leave a minimum of one cartridge diameter between each cartridge);

  (iv) the cartridges are not piled on top of each other; and

  (v) the maximum quantity of explosives in each individual trail is not more than 12 kg.

(f) Remove any explosive that is not to be burnt to a distance of at least 300 m and place it where it cannot be hit by any fly or flyrock that might occur during the burning.

(g) Use slow igniter cord as a wick or, if it is not available, make a wick out of sheets of paper loosely rolled together. Lay out and attach the wick to the downwind end of each trail. The wick should be an extension of the trail.

(h) If igniter cord is used as a wick, one end should be coiled within the trail. If a paper wick is used, ensure that at least 1 m of it is in contact with the trail. The wick should be secured so that it cannot be accidentally dislodged by the wind after lighting.

(i) The length of the wick should be sufficient to allow the person(s) lighting it to retire to the predetermined safe place after it has been lit.

(j) Thoroughly wet the trail and the explosives (and the paper wick) with kerosene or diesel (never petrol or other highly flammable liquid) (see Note 6).

(k) Implement the exclusion zone if not already established.

(l) Implement the predetermined safety procedures, light the wick and retire to the predetermined safe place (see Note 7).

(m) Do not return to the site for at least 15 min after the burning has apparently finished.

(n) If the fire goes out before any trail has finished burning, do not approach for at least 15 min after all trace of fire has apparently gone.

(o) Do not add more kerosene or diesel while there is any potential for re-ignition during application.

NOTES:

1 This may need to be during the delivery or preparation stage of the work. The condition of the explosives and the quantity to be burned can influence the decision making process.

2 The size of the exclusion zone should be large enough to allow for the possibility of an explosion occurring during the burn.

3 The trail(s) should be aligned such that the flame from the trail and the burning explosives will blow away from the unburned explosives as detonation is more likely to occur if the explosives are preheated by the flame.

4 Some emulsion and water-gel explosives are difficult to burn and may require additional fuel. The manufacturer or supplier should be contacted if large quantities of these explosives are to be destroyed.

5 Puncture marks in the side or the end of a cartridge can indicate the possible presence of a detonator.

6 The use of excess fuel will only soak into the ground and unnecessarily prolong burning that might not include explosives.

7 If more than one wick is to be lit, it is recommended that either the wicks are joined or a multiple fuse lighter is used.

H1.2 Variations for other explosives

H1.2.1 *Detonating cord*

Detonating cord should not be burnt on a reel or spool but cut into lengths, or loosely coiled, and placed on top of the trail(s) as for cartridged explosives. It should be burnt in lots not greater than the equivalent of two 10 g/m reels at a time or a maximum of 1000 m, whichever is the lesser. Extreme care should be taken to ensure that there are no detonators or detonating delay devices attached to any part of the detonating cord.

H1.2.2 *Safety fuse*

Other than a possible fire or pollution hazard, there is little danger with safety fuse, provided that care is taken to ensure that it is free of detonators. It may be destroyed by burning on an open fire.

H1.2.3 *Igniter cords*

When burning igniter cord it should be completely uncoiled from its spool. It will not need fuel to assist in the burning process and an area well cleared of flammable material is necessary as it can whip violently during burning. A length of safety fuse is recommended as a wick as it will allow the person lighting it to be well clear prior to the igniter cord commencing to burn.

APPENDIX I

EXTRANEOUS ELECTRICITY

(Informative)

I1 SCOPE

This Appendix provides guidance on the source of various forms of extraneous electricity and sets out recommendations on preventive measures, paying particular attention to stray currents and static electricity. It also suggests appropriate distances between electro-explosive devices and sources of radio frequency radiation (see Table I1).

I2 SOURCES OF EXTRANEOUS ELECTRICITY

Extraneous electricity may result from both natural and man-made situations, as follows:

(a) *Lightning* Lightning is a high energy source capable of initiating explosives. The situation may be aggravated if there are conductors in the vicinity of the point of the lightning discharge that lead to the loading site, e.g., conductive ore body, water pipes or other services, rail tracks, fencing wires.

(b) *Induced currents, capacitive discharge* Induced currents may be present in areas such as around power stations and earth loop transport systems (rail, trams, trolley locomotives). Capacitive discharge may occur where high voltage transmission lines charge a suspended, above-ground blasting circuit to a high voltage. This voltage may then be discharged to earth through a detonator thus causing a premature explosion.

(c) *Accidental earthing* If there is an accidental earthing of a power transmission line in the vicinity of a circuit, a premature explosion might occur.

(d) *Transmitters* When using electric initiation, there is a possibility of the blasting circuit being energized by the electric field produced by radio transmitters, radar, television transmitters or the like. Table I1 provides recommendations for safe distances.

(e) *Static electricity* While electrostatic charges are among the most common phenomena in nature and the mechanism of the formation of the charges is controversial, the potential for an electrostatic charge to initiate a detonator or black powder is very real.

For a dangerous condition to exist, three criteria have to be met, as follows:

(i) A capacitor-like object needs to be charged to a potential (voltage) such that the electrical energy stored in this system is large enough to cause initiation when released as a discharge. For example, the capacitor can be a person or ANFO loading equipment.

(ii) The capacitor has to lose its charge to cause ignition.

(iii) The path of this discharge needs to be sufficiently close to the sensitive material to cause ignition or initiation.

As it is difficult to control Items (ii) and (iii), Item (i) offers the best potential for introducing preventive measures and thus minimizing an electrostatic charge build-up.

I3 GENERAL PREVENTIVE MEASURES

The possibility of premature initiation from extraneous electricity is always a potential hazard. Where extraneous electricity is suspected or evident, detailed information should be sought from the manufacturers as to the suitability of their products and initiation systems in particular circumstances. Some preventive measures applicable to all initiation systems are as follows:

(a) Use a non-electric initiation system.

(b) Ensure all bare connectors in, or to be used in, a circuit are kept short-circuited by twisting the ends together until final connection.

(c) Avoid situations that might generate and store static electricity.

(d) Take special care to ensure that bare lead wires do not come into contact with the ground and that connections are either insulated or kept clear of the ground.

(e) Cease all surface charging operations if an electrical storm is imminent. If working underground, assess any possible dangers from lightning and take appropriate action.

(f) Keep detonators clear of the ground until charging commences.

Specific recommendations on stray currents and static electricity are provided in Paragraphs I4 and I5.

I4 STRAY CURRENTS

I4.1 General

Under certain conditions there may be a possibility that stray electrical currents might initiate premature detonation. As a guide to determining the possibility of such currents existing on a particular site, the following information is included:

(a) Where electrically operated equipment, including welding equipment, is used, it is possible for stray currents to be generated from faulty circuits and equipment. These currents may pass through the ground itself as well as continuous metal objects such as haulage rails, pipelines, ventilating ducts or wire ropes.

(b) As the minimum firing current for electric detonators is 250 mA, tests for stray currents should be sensitive to at least 60 mA, a.c. or d.c.

(c) Tests for stray currents should be carried out in advance of electric firing, particularly in highly conductive ground or where continuous metal objects extend up to the area being charged with explosives. A suitable test is given in Paragraph I4.2.

(d) In mining operations, any electric welding being carried out on rail track, steel ground support or the like should be halted prior to any electrical detonators being transported into the tunnel either in an explosives car or by other means. Welding should not recommence until the blasting operation has been safely completed and any surplus detonators returned to the explosives magazine.

I4.2 Testing for stray currents

A high impedance (10 MΩ or more) voltmeter should be used to test for stray currents. Two probes made of identical material 25 mm in diameter and 200 mm long should be driven into the ground or placed between the locations in question being tested, e.g., damp spots, pipes, rails, conductive ore bodies. Stainless steel is recommended for probes.

As any source of potential can be dangerous (whether caused by stray currents or something else) it is advisable to try to locate the greater potential difference within a radius of 1 m to 2 m from the point where the detonator leads are likely to be placed. Once the highest potential difference has been found, a low-impedance ammeter (1 Ω or less) should be placed across the probes and the current recorded. If the current is less than or equal to 60 mA, the situation is reasonably safe. If the current is more than 60 mA, special precautions should be taken to ensure the bare lead wires cannot come in contact with the ground. Where possible, all stray currents that are found should be eliminated.

It is advisable to test for stray currents over a period of time in order to be aware of fluctuations, which may become more pronounced when heavy equipment is started or operated in the vicinity of the test area.

I5 STATIC ELECTRICITY

I5.1 General

Dangerous levels of static electricity may be generated in a number of ways, for example by dust storms, snowstorms, moving conveyor belts, the pneumatic loading of free-flowing granular explosives or sand stemming into blastholes and even the action of pouring free-flowing granular explosives from a plastic container into paper cartridges or from the use of plastic borehole liners.

I5.2 Dusty conditions, snowstorms

In a dry, dusty atmosphere, for example over a desert, the accumulation of static charges may be substantial during dust storms. This may also apply during dry drifting snowstorms. Although it is desirable to suspend all blasting operations during storms, these are often of such duration that practically no work would be possible for days on end. This applies most often in seismic work, and certain precautions should be observed if work must be done under these conditions. The recommended procedure to be adopted is as follows:

(a) Lay out the shotfiring cable.

(b) Short-circuit both ends and connect both to earth, say by driving a metal rod into the ground, and wetting the ground if it is very dry.

(c) Short the detonator leading wires and attach their ends to earth.

(d) Uncoil the leading wires carefully and lay them along the ground. The wires must not be thrown and, in uncoiling, the operator should handle the portion of the wire adjacent to the detonator tube, not the tube itself. The operator should be earthed before handling the detonator tube prior to insertion in the explosive, to prevent possible sparking from tube to fusehead.

(e) Lower the charge into the blasthole as far as the leading wires will allow.

(f) Disconnect the leading wires from the earthed rod and connect them to the leads of the shotfiring cable, which should also have been disconnected from earth.

(g) Do not disconnect the other end of the cable from earth until ready to fire.

(h) When operating near electric power lines, make sure that the leading wires and shotfiring cable are securely anchored and placed so that they cannot be blown across the power lines by the explosion.

I5.3 Other static electric hazards

The following precautions should be taken to deal with other static electric hazards:

(a) All machinery near the blasting area should, where possible, be well earthed.

(b) The wiring of the shotfiring circuit should be separated from large conductors such as rails or piping and be protected and isolated with good insulation.

I5.4 Pneumatic loading of free-flowing granular explosives

Before free-flowing granular explosives or dry stemming is pneumatically propelled into blastholes that have been, or will be, primed with electric detonators, the following precautions should be taken:

(a) Earth all pneumatic charging equipment. Where conditions are dry or the equipment is separated from earth, provide special earthing cables with, if necessary, a spike which is driven into the ground.

NOTE: Earth contact can be greatly enhanced by wetting with water or, preferably, with a solution of common salt or ammonium nitrate in water.

(b) Equip the loader with a semi-conductive hose to discharge static to earth and prevent the build up of high voltages.

(c) Check that the total resistance of the equipment and earth return is not more than 10 MΩ or otherwise conforms to the requirements of the regulatory authority.

(d) Do not use plastic liners in blastholes unless they are genuinely and permanently conductive.

(e) Before starting to collar prime or connect up the detonator lead wires, the shotfirer should withdraw the loading equipment, take off any protective gloves being worn and be earthed.

It should also be noted that in certain circumstances a person can generate and hold enough charge to fire a detonator.

TABLE I1

SINGLE SOURCE SAFE DISTANCES FOR ELECTRIC DETONATORS SUBJECT TO RADIO FREQUENCY RADIATION (See Note 1)

Description of equipment	Frequency range	Maximum transmitted power	Safe distance (see Note 3) m
Radar	>5 GHz	100 kW peak	500
Radar	1 to 5 GHz	6 MW peak 50 kW continuous work	800
Radar	0.2 to 1 GHz	6 MW peak 50 kW continuous work	1500
SHF: radio relay	≥3 GHz	20 W	80
VHF: radio relay	0.3 to 3 GHz	20 W	150
UHF: fixed installation: broadcast	≥ 0.3 GHz	5 MW	600
UHF: movable (see Notes)	≥ 0.3 GHz	50 kW	150
VHF: fixed, broadcast	30 to 300 MHz	50 kW	900
VHF: movable	30 to 300 MHz	5 kW	150
HF: broadcast	3 to 30 MHz	500 kW	1000
MF: broadcast	0.3 to 3 MHz	500 kW	1000
LF: broadcast	30 to 300 kHz	500 kW	500
VLF: broadcast	<30 kHz	200 kW	100
Mobile radio	Any frequency	100 to 500 W	40
Mobile radio (see Note 7)	Any frequency	10 to 100 W	20
Mobile radio	Any frequency	<10 W	20
Mobile phones	800 to 2100 MHz	0.125 to 2 W	20
Microwave ovens or high-frequency ovens (providing there is no significant r.f. leakage)			No hazard outside the equipment
Civil aircraft equipment. All types at maximum permitted power.			50

NOTES:

1 Table I1 sets out recommendations for safe distances for blasting from electromagnetic radiation when electric detonators are being used to detonate explosive charges. These distances may not apply under desert and marine conditions, where special shotfiring methods adopted may give rise to worse hazard. If two or more significant field sources are superimposed at the firing site a safety assessment should be carried out.

2 If there are two or more significant transmitting sites radiating powers in excess of 50 kW, each within 3000 m (see also Note 3 of the firing site, then a detailed site assessment should be undertaken.

3 The tabled distances do not necessarily apply to transmitters utilizing 'troposcatter'.

4 The distances apply directly in the case of standard commercial detonators with leads unwound or partially unwound during normal handling and when connected into firing circuits. The distances are from the transmitter to the nearest point of the proposed firing circuit.

5 This Table may require amendment as further information on radiation sources becomes available.

6 'Movable' implies vehicle-borne equipment, which requires erection of a portable aerial for operation.

7 'Mobile' implies capable of operation whilst vehicle is moving (seagoing vessel radios should not be assumed 'mobile' in this context).

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.

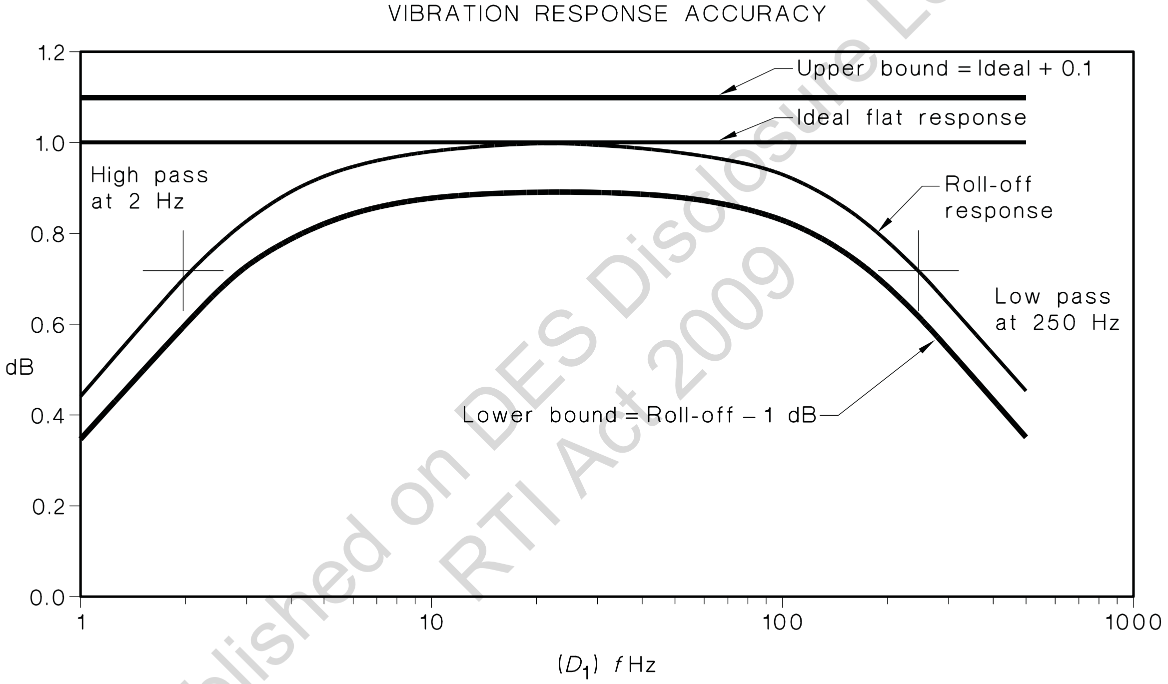


FIGURE J3.2.1 TYPICAL PARTICLE VELOCITY VIBRATION RESPONSE ACCURACY

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.

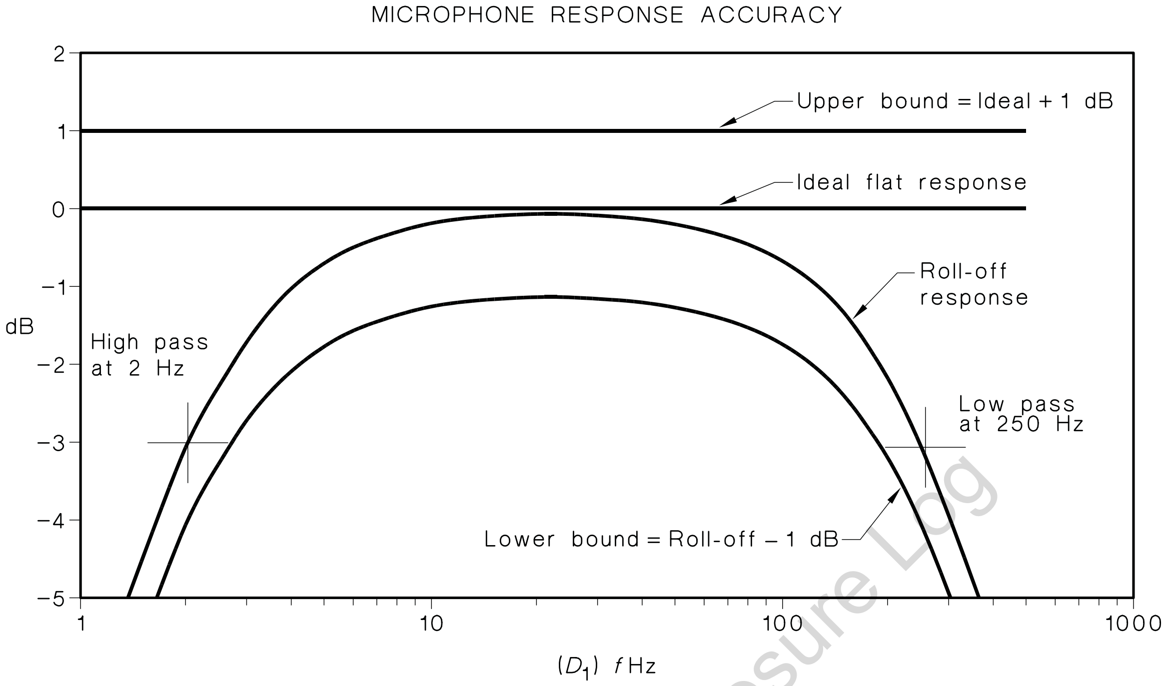


FIGURE J3.3.1 MICROPHONE RESPONSE ACCURACY

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:

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

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.

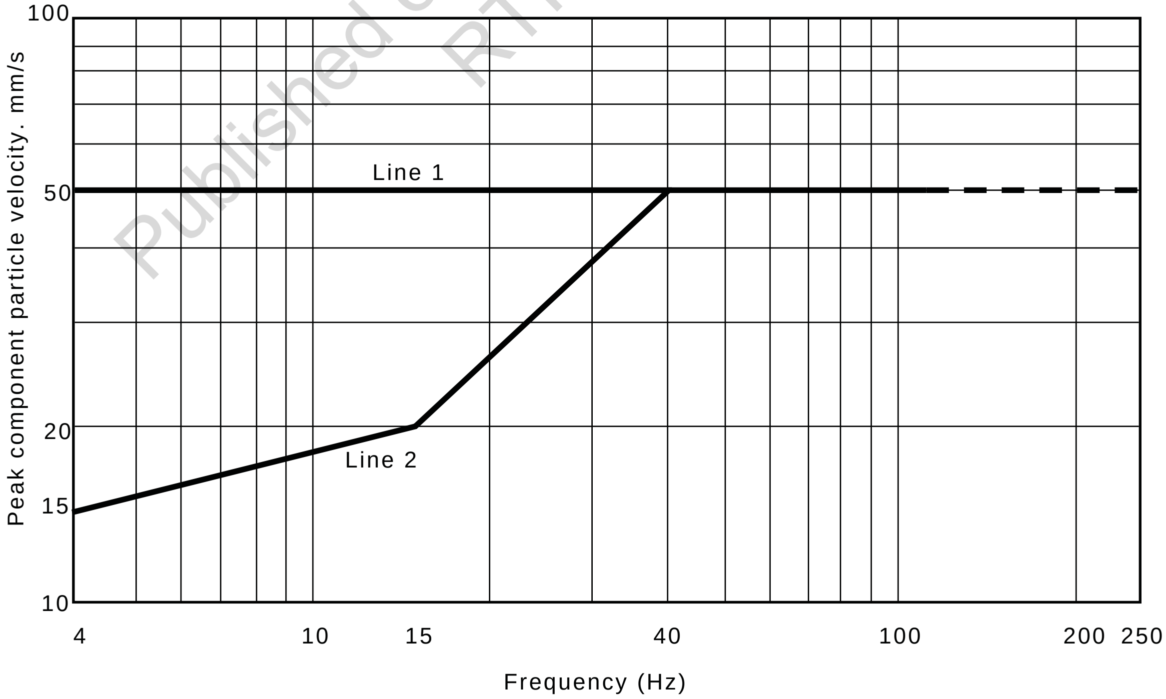


FIGURE J4.4.2.1 TRANSIENT VIBRATION GUIDE VALUES FOR COSMETIC DAMAGE (BS 7385-2)

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.

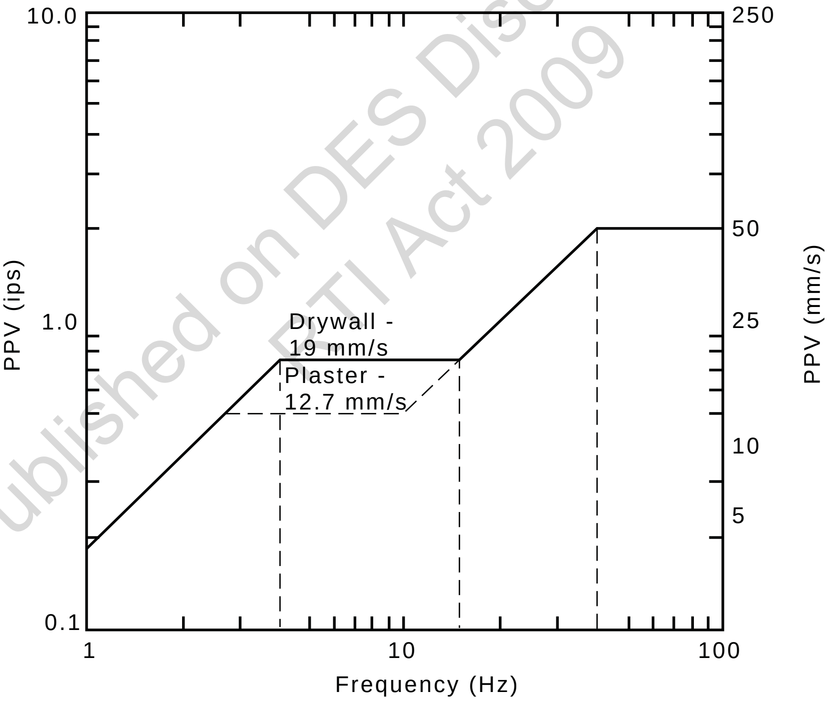


FIGURE J4.4.2.2 USBM 'SAFE' BLASTING VIBRATION LEVEL CRITERIA

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.

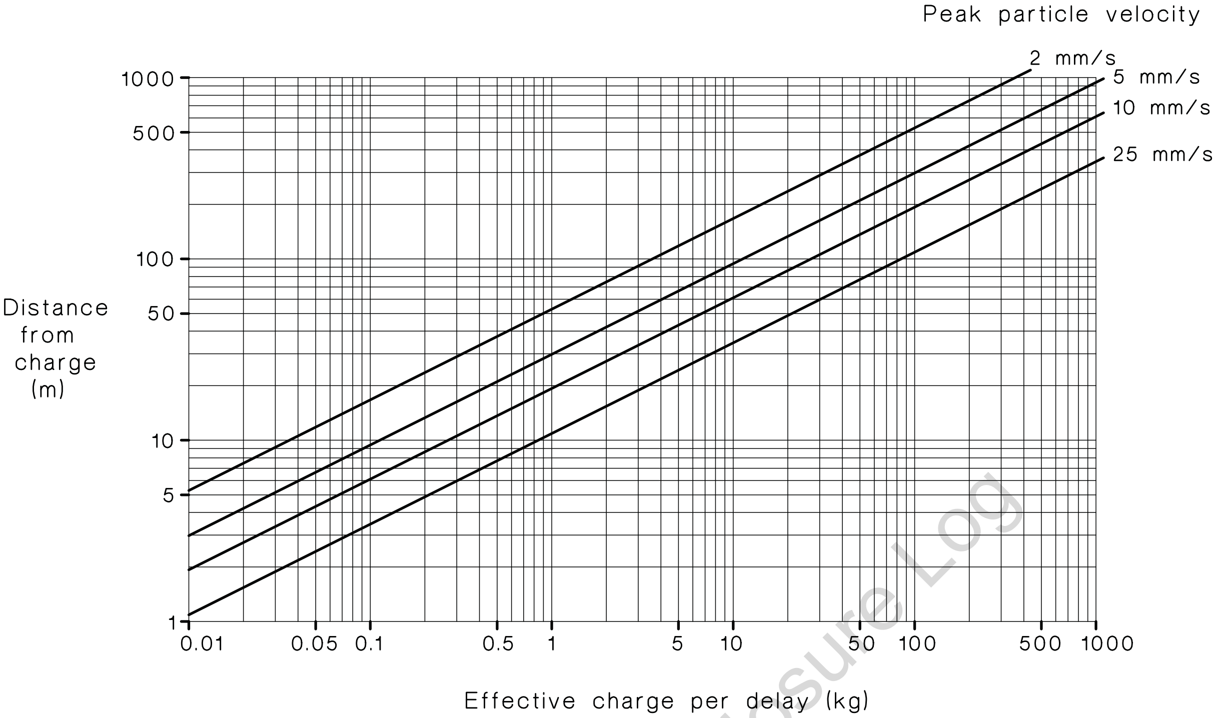


FIGURE J7.3.1 FREE-FACE—AVERAGE FIELD CONDITIONS

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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APPENDIX K

DEMOLITION OF STRUCTURES

(Informative)

K1 GENERAL

The application of explosives for structural demolition requires extensive planning and preparatory work and should only be performed by competent persons. This Appendix is not intended to provide procedures for explosive demolition but rather recommendations to be considered in the interests of health, safety and welfare of persons, property and the environment.

K2 PRINCIPAL CONSIDERATIONS

The principal considerations in structural demolition are achieving the intended collapse mechanism, the safety of persons, property and the environment, and the minimization of—

(a) fly;

(b) airblast overpressure;

(c) dust;

(d) ground vibration; and

(e) ground compression or ground penetration from parts of the collapsing structure.

Some examples of what may influence any intended use of explosives include—

(i) materials of construction;

(ii) services, e.g., water, gas, electricity, sewerage, drainage, communications, subways on, below or adjacent to the site;

(iii) adjacent buildings or structures—

  (A) buildings housing sensitive equipment;

  (B) hospitals, nursing or retirement homes;

  (C) animal or wildlife shelters, stables, veterinary hospitals, zoos;

  (D food processing establishments; and

  (E) heritage items.

(iv) occupants of adjoining buildings;

(v) adjoining dangerous goods plants or storages, e.g., flammables, chemicals;

(vi) adjacent transport systems including roads, railways, waterways and flight paths; and

(vii) public places.

K3 NOTIFICATION

The following may need to be notified:

(a) Regulatory authorities having jurisdiction.

(b) Emergency services including Police, Ambulance and Fire.

(c) Gas supply.

(d) Electrical supply.

(e) Telecommunications.

(f) Sewerage, drainage and water supply.

(g) Transportation system authorities.

(h) Fisheries or inland waters.

(i) Adjacent property owners and occupants who may be affected by the blast.

As part of the planning process, Police should always be informed. As the usual first line recipients of complaints or reports regarding a disturbance such as those created by explosive demolition, it is imperative they be aware of work of this nature.

K4 EXAMINATION OF THE STRUCTURE

As part of the planning process, structural drawings, where available, should be examined and the materials of construction confirmed by physical examination or testing or both. The preparatory work for each structure will vary considerably. Supporting documentation from a structural engineer should be obtained to identify the key members providing the stability to the structure and the effect on structural or load-bearing members when altered, cut, weakened or removed. Particular attention should be paid to the following:

(a) Location of all gas, water, electrical, and communication services that may require disconnection.

(b) Identification of all asbestos and asbestiform material including asbestos-cement sheeting.

(c) Identification of materials that may plane or glide if they break free, e.g., roofing, iron, cladding, panes of glass.

(d) Identification of construction of non-structural walls, beams, and the like that may interfere with the intended line of fall or collapse.

K5 EXAMINATION OF THE SURROUNDING AREA

As part of the planning process, the area surrounding the structure should be examined. This area or zone also includes the area within site boundaries under the control of the demolition contractor as well as the area outside the site boundaries. The purpose of the examination is to identify critical facilities or services that might be adversely affected by the demolition and are situated below, at or above the surface. The shape of the zone will approximate a hemisphere depending on the topography of the environment. The actual size of the area to be considered will be dependent on the type of structure and materials of construction, intended collapse mechanism, type of charges and initiation delay system, likely fly projections, airblast overpressure predictions, type of structures and facilities in the surrounding area, and potential for spectator viewing points. It is probable that the examination will require consultation with regulatory authorities, local government agencies, police and emergency service providers, energy and communication system providers, transport agencies, owners and occupiers of surrounding properties, and interest groups including those who may be opposed to the demolition. Considerations should include, but not be limited to, the following:

(a) Flight corridors and flight schedules.

(b) Surface transport corridors including routes that may need to be closed during the demolition and the effect this will have on emergency service vehicles and special services such as school buses.

(c) Maritime corridors and waterways.

(d) Location and type of energy systems including monitoring or control stations.

(e) Identification of facilities that may need to be evacuated or cannot be evacuated such as hospitals.

(f) Identification of structures that have critical responses to ground or water vibrations such as dams, power generation systems, hospitals, high-rise buildings and pre- or post-stressed concrete structures such as bridges.

(g) Identification of walking tracks, likelihood of spectators and potential viewing points.

(h) Identification of areas containing livestock or animal refuges.

The key outcome will be to identify whether the surrounding area can be secured and then controlled for the duration of the demolition.

K6 DEMOLITION BLAST PLAN

The demolition blast plan, which may form part of an overall demolition workplan, should include, but not be limited to, the following:

(a) Name and location of the project and relevant permits/licence.

(b) Location of the proposed blasting.

(c) Identification and position of the person responsible for the project including project safety.

(d) Identification and position of person who has given approval to use explosives on the project.

(e) Shotfirer's details.

(f) Acknowledgement of communications with any of the authorities listed in Paragraph K3.

(g) Description of the proposed blasting.

(h) Details of adjacent structures or services that may influence the blast design.

(i) Details of the risk management procedures.

(j) Details of reports, drawings and records consulted, including material tests.

(k) A plan of the area showing details of facilities listed in Paragraph K2.

(l) A plan of the structure showing the weight/type of charges, their placement and delay times.

(m) Blast sequence in detail, which includes the following:

    (i) Communications systems.

    (ii) Placement of warning signs.

    (iii) Security of the area before, during and after the blast.

    (iv) Signal systems and timing.

    (v) Personnel exclusion zones.

    (vi) Evacuation procedures.

    (vii) Monitoring procedures for both airblast overpressure and ground vibration as appropriate.

    (viii) Crowd control.

    (ix) Pre-blast final inspection.

    (x) Post-blast inspection.

(xi) All clear.

(n) Explosive loading/detonation sequence/effective charge mass per delay (MIC).

(o) Security procedures for the blast including overnight security when required.

(p) Environmental considerations for airblast overpressure, ground vibration (see Appendix J) and fly (see Appendix E).

(q) Explosive storage and handling procedures.

(r) Warning procedures.

(s) Contingency plan.

(t) Misfire procedure.

(u) Method of notification to owners or occupiers of structures and services adjacent to the blast.

(v) Proposed methods to be used to minimize/prevent fly of debris.

(w) Procedures, if required, to be taken to protect any of the services listed in Paragraph K2.

(x) Proposed dates and times of demolition.

(y) Confirmation of advice to police and other appropriate authorities when initiation time is known.

(z) Proposed exclusion zone including authority to close/restrict and reopen transport systems.

(aa) Comments on plan.

(bb) Signature space for applicant, shotfirer and person who approves the plan.

(cc) Weather details.

(dd) Provision for post-blast comments.

K7 CONTINGENCY PLANNING

A contingency plan is prepared in case the operation does not proceed as planned. This should take account of personnel evacuated from nearby properties and road closures. Also the provision of standby plant, equipment, additional explosives and material used to contain fly in case the structure does not collapse as intended or a misfire occurs. Contingency plans should be discussed at the planning stage.

K8 EXPLOSIVES

Attention should be paid to the following:

(a) Using only appropriate explosives and techniques designed for a specified task as recommended by the manufacturer.

(b) Using a proven powder factor, noting that a structural member that is not cut, removed or weakened as intended can interfere with the intended collapse mechanism.

(c) Conducting a test shot to ascertain the strength/suitability/powder factor of an explosive for its designated task.

(d) Providing adequate cover around the charges to prevent/minimize fly of debris and airblast.

K9 INITIATION SYSTEMS

Particular attention should be paid to the following:

(a) Where delays are required, using only electric or signal tube initiation systems.

(b) Not using signal tube initiation if there is a possibility of the signal tube being severed by fly from an earlier blast before the signal reaches the detonator.

(c) Not using detonating cord in conjunction with delays.

(d) Not using safety fuse to provide delays.

(e) Ensuring all detonators and their primers are protected, cannot be separated from each other and that the units cannot be dislodged by airblast, fly or structure movement.

(f) Using a back-up (second) initiation system to positively ensure initiation of all the charges, e.g., with electrical initiation, two series circuits connected in parallel; with signal tube, using a second circuit initiated simultaneously with the primary circuit.

APPENDIX L

EXCLUSION ZONES

(Normative)

L1 GENERAL

All blasts require the establishment of an exclusion or evacuation zone prior to firing the shot. Depending on the industry, the zone can be the area, below, at and above ground level, from which all unauthorized persons are excluded to protect them from injury or harm.

The size of the exclusion zone shall be such that all fly and associated debris is contained within the zone, as well as consideration on impacts of blast environmental limits on humans and where required, animals.

The effects of dust should be minimized.

An exclusion zone can comprise an inner zone, which is established prior to the commencement of loading the shot, and an outer zone that adjoins the boundary of the inner zone, and is established prior to the final connections being made or programming of electronic detonators. The purpose of the inner zone is to allow work to continue in surrounding areas during loading, but must be controlled to prevent unauthorized access of personnel, plant and equipment.

The inner zone shall be identified by being cordoned off with flagging tape, flags, hazard blast cones, berms, signage or other suitable means visible at all times to restrict unauthorized entry.

The shotfirer and authorized persons may remain in the exclusion zone, at a predetermined protected location during firing. Final approval for persons to observe or monitor the shot from within an exclusion zone remains with the shotfirer, who should not be subject to any external pressure.

L2 PLANNING

The requirements for an exclusion zone shall be a component of the blast management plan. The degree of planning will be dependent on the industry, for instance the ventilation system of an underground mine will influence an exclusion zone in three dimensions.

For blasting operations where the zone is contained within property boundaries (subject to airspace clearances) or underground, standard procedures may be developed and implemented for each blast.

For blasting operations where the zone is on or extends onto neighbouring property, each blast will be unique and the feasibility of establishing an exclusion zone that extends beyond the site boundary shall be investigated. This may require liaison with project management staff, regulatory authorities, emergency service providers, local landowners, transport authorities (land, maritime and air), energy service providers, and any other affected body. The effect on animals shall be considered, as noise from a blast can cause distress resulting in injury or death. Existing facilities and energy systems within the exclusion zone may need to be protected as fly can cause significant damage. Approvals from regulatory bodies and other authorities may be required.

If a zone of the required size cannot be established and controlled for the expected timeframe, then another method of carrying out the task shall be considered.

L3 SIZE OF THE EXCLUSION ZONE

The size of the exclusion zone is directly related to the blasting activity and the surrounding environment. For example, an exclusion zone for structural demolition would differ considerably to a remote agricultural blast and similarly for underground or maritime work.

The distance required to limit airblast overpressure to tolerable levels can be estimated, but the distance for fly can be difficult to predict and can vary from site to site. Therefore a competent person shall determine the size of the zone, in many cases through extensive consultation with other stakeholders. The zone may be larger than the calculated size to make use of control points such as transport junctions, or elevated areas that provide clear lines of observation.

On public roads when deciding the location of traffic control points, areas that are difficult for impatient drivers to bypass once stopped shall be identified. Examples of such bypasses include the potential to move to another lane or drive across the median strip to another carriageway and then drive through the exclusion zone. Temporary barriers may be insufficient to stop such drivers and physical blockages such as plant may be necessary. The control point shall be sited so that there is adequate stopping sight distance for drivers, enhanced by the use of warning signs. A minimum of two people should be assigned to each traffic control point with one person moving along the stationary line of traffic to inform drivers how long the delay is likely to be. Where alternative routes allow safe bypass of the exclusion zone, signs shall be erected prior to the junction.

For contract work, the contract documentation should include the requirements for an exclusion zone, but distances should not be stipulated unless they have been determined by a competent person and are known to be achievable within the surrounding area.

L4 ESTABLISHING AND DISESTABLISHING THE ZONE

Written procedures shall be developed for the establishment and disestablishment of the exclusion zone. Content, where applicable, should include, but not be limited to the following:

(a) A description of the zone and method of implementation.

(b) Details of organizations involved.

(c) A list of key personnel outlining tasks and responsibilities.

(d) A list of other personnel, outlining tasks and responsibilities.

(e) A description of the means of communication.

(f) A procedure to control radio transmissions that may influence the communication or security of the shot.

(g) Timings and procedures for notification of agencies on-site and off-site such as emergency service providers.

(h) A procedure to activate in the event of inclement weather or lightning.

(i) Identification of the location of, and the method of manning of, control points.

(j) Procedures to clear areas such as public roadside rest areas, toilets and underside of bridges that are located within the zones.

(k) A method to establish and notify the shotfirer that the inner and outer zones have been cleared.

(l) A method to control livestock or wildlife.

(m) Identification of, and contact details for, liaison with bodies who control the approval to fire, such as air traffic control.

(n) Procedures for passage of emergency vehicles such as police, fire and ambulance.

(o) Procedures for immediate notification of and dealing with trespassers.

(p) Warning procedures prior to firing.

(q) Procedures to remove fly or debris that may fall on roads or other areas.

(r) Procedures for misfires.

(s) Safety and security procedures for the shot remaining loaded overnight.

(t) A procedure to identify that fumes have cleared to safe levels in underground work areas.

(u) A method of notification to return the whole of the exclusion zone to normal.

(v) A method of notification to disestablish the outer zone, only.

Site briefings shall be conducted for personnel involved with the establishment and disestablishment of an exclusion zone. If different organizations provide personnel, the same pool of people should be used when the operation involves blasting over a period of time. Rehearsals should also be considered.

When a shot cannot be initiated and is to remain loaded overnight, the firing circuit shall be made safe. Under these circumstances the exclusion zone can be based on the inner zone provided the area is secured prior to returning the outer zone to normal. When a site requires guarding, personnel other than the shotfirer and crew, shall be engaged to ensure that the shotfirer has sufficient rest prior to firing the next day. Such personnel shall be briefed on hazards and a procedure for contacting a responsible person in the case of trespass.

The exclusion zone should not be returned to normal until the ‘all clear’ for the blasting operation is given by the shotfirer.

L5 SPECTATORS

The use of explosives in some industries can attract spectators and possibly demonstrators along with strong media involvement. Such possibilities shall be considered for the control and size of the exclusion zone. It is important that control is established and maintained at all levels of the project and the blasting operation should not be promoted as a public display.

For surface work it may be preferable to fire on weekdays rather than a weekend or near a public holiday, as this may reduce the potential for spectators. Where the operation is adjacent to a school bus route, the shot should be fired by early afternoon to avoid delays. In addition, support can be more readily obtained if a difficulty arises, e.g., a misfire.

Where notification has to be given in advance to the public, such as road closures, it is preferable for reasons of security not to mention the use of explosives. Similarly, if the method of firing does not involve electric detonators, signage on explosives relating to transmitters may not be required.

NOTES

NOTES

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Standards Australia is an independent company, limited by guarantee, which prepares and publishes most of the voluntary technical and commercial standards used in Australia. These standards are developed through an open process of consultation and consensus, in which all interested parties are invited to participate. Through a Memorandum of Understanding with the Commonwealth government, Standards Australia is recognized as Australia's peak national standards body. For further information on Standards Australia visit us at

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Customer Service Phone 1300 65 46 46 Fax 1300 65 49 49 Email sales@standards.com.au
Internet www.standards.org.au

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Sent: Monday, 31 October 2016 8:46 AM
To: ROWE Sarah
Subject: ehp-letter-template-letterhead
Attachments: ehp-letter-template-letterhead.docx

For eDOCS please. Signed copy on its way.

Queensland Government
Department of
Environment and
Heritage Protection

Ref CR72122

31/10/2016

Standards Information Service
Standards Australia
Level 10, The Exchange Centre
20 Bridge Street
Sydney NSW 2001

Dear Sir / Madam

The Queensland Department of Environment and Heritage Protection (the department) has been investigating complaints about blasting at a quarry in Mt Coot-tha, an inner suburb of Brisbane in Queensland Australia. Complainants allege that blasting has impacted residential dwellings which have been constructed in recent years in relatively close proximity to the quarry.

Australian Standard 2187.2 “*Explosives- Storage and Use, Part 2: Use of Explosives*” has been referred to by consulting professionals, the community and the department at various times during the complaint investigation. Most recently, the community has raised concern that AS2187.2 does not provide guidance in relation to impacts from blasting over an extended period of time, nor in upper levels of 2 and 3 storey residential dwellings.

Whilst the department notes that Table J4.5(a) mentions sensitive sites and includes guidance for blasting that exceeds 12 months or more than 20 blasts, members of the community are concerned that vibrations from quarry blasting that exceeds 10 years and hundreds of blasts may have implications for structural integrity of homes and amplification of vibration and overpressure, even when ground vibration is within the 5 - 10mm/s spectrum as measured by a professional consulting firm.

The department understands that members of the Mt Coo-tha community are preparing a submission to Standards Australia. Whilst the department is not seeking to endorse the community submission, the department does note that clear guidance regarding long term blasting and impacts within upper levels of 2 and 3 storey residential premises is worthy of consideration by Standards Australia within AS2187.2.

Level 4
33 King Street Caboolture
PO Box 808 Caboolture
Queensland 4510 Australia
Telephone + 5316 8403
Page 1 of 2
Website www.ehp.qld.gov.au
ABN 46 640 294 485

Should you have any further enquiries, please contact me on telephone 5316 8403.

Yours sincerely

Matt Karle
Compliance Delivery Manager, South Queensland Compliance – Brisbane Moreton Bay
Environmental Services and Regulation
Department of Environment and Heritage Protection

Queensland
Government

Department of
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Queensland 4510 Australia
Telephone **+ 5316 8403**
Page 1 of 2
Website www.ehp.qld.gov.au
ABN 46 640 294 485

Should you have any further enquiries, please contact me on telephone 5316 8403.

Yours sincerely

sch4p4(6) Personal Information

Matt Karle
Compliance Delivery Manager, South Queensland Compliance – Brisbane Moreton Bay
Environmental Services and Regulation
Department of Environment and Heritage Protection

BRISBANE CITY
Brisbane City Council ABN 72 002 765 795
Dedicated to a better Brisbane

14 September, 2016

Mr Andrew Connor
Executive Director
Industry, Development and South QLD Compliance
Department of Environment and Heritage Protection
Via Email: ESComplianceBrisbaneMoreton@ehp.qld.gov.au

Re: Mt Coot-tha Quarry Blasting Activities EPPR00447313

Dear Mr Connor

I refer to your correspondence dated 26 July 2016 and received via email on 16 August 2016 in which the Department asked Council to consider voluntarily reducing blast and vibration limits.

For economic and environmental reasons, this simply is not possible. We outline why below.

Value to Council and the State

Quarry operations in various forms have existed at this site since the late 1800's and the site has been operated by Brisbane City Council since its formation in 1924. Mt Coot-tha Quarry is a key asset for Council that continues to provide cost effective, high quality asphalt aggregates to support the needs of all residents and visitors to Brisbane.

The Mt Coot-tha Quarry directly employs approximately 20 people and indirectly supports at least 15 contractors and suppliers.

As you would be aware Mt Coot-tha Quarry is recognised by the Queensland Government as a Key Resource Area known as KRA42. Matters relating to the protection and administration of extractive resources that are deemed state significant are covered under State Planning Policy. In April 2016, KRA42 indicates 'The resource is sufficient for another 12-16 years based on current production rates.' This is in keeping not only with Council's intended use of the quarry but also with information given to the local community. Contrary to a comment in your correspondence, Council has not resolved to further extend the life of the quarry beyond this time.

Council operates Mt Coot-tha Quarry with a self-imposed production cap of 410,000 tonnes per annum. This cap has been in place since a significant community consultation process was established in 2002, following the extensive supply of materials during the construction of the Inner City Bypass. Council informed the community at that time that the extractive life of the quarry was at least until 2033.

Accordingly, with respect, Council considers your Department has made an incorrect statement in its correspondence:

> *In addition to residential proximity and technological advancements, a recent decision by BCC to extend the quarry life has increased community expectation that the quarry will demonstrate continual improvement and comply with best practice noise and vibration limits.*

Against that background, Mt Coot-tha Quarry has a long history of environmental compliance and it continues to operate in accordance with the conditions of its prescribed environmental authority EPPR00447313.

Adverse environmental and economic consequences should blast and vibration limits be reduced

DEHP's suggestion to further limit the site by reducing blasting and vibration limits raise the following significant issues for Council:

1. Council has a demonstrated history of compliance to existing environmental conditions and has invested, planned and developed the quarry operations around existing approval conditions.

2. As discussed above, Council has already implemented a production cap which places significant commercial burden on the operations of the quarry. Operating the quarry at this production limit substantially reduces the environmental and community impact of Mt Coot-tha Quarry. However further reducing the blasting and vibration limits may make the quarry operations uneconomic and may even cause the quarry to close before 2033 at significant cost to the Brisbane ratepayer.

3. Quarry management have initiated and incorporate 'best practice' blasting design and techniques into the operations. Each blast is specifically designed to reduce the impacts beyond the site boundaries. I note your letter suggests that Council is not adhering to best practice for noise and vibration. In this respect, Council considers that it already complies with the Department's Guideline – Noise and vibration from blasting.

   Furthermore, Council engages third party experts to design, monitor and provide oversight of the quarrying operations. These experts have considerable national and international experience and are renowned for being industry leaders. We respectfully disagree with any suggestion that this quarry is not operated at best practice.

4. Blasting is the most effective method of fracturing hornfels stone prior to further processing. As you would appreciate, hornfels stone is exceptionally tough. Reducing blasting limits creates further economic and environmental burden to the operations of the quarry. Reduced blasting limits will result in:

   a. increased oversize rock generation;

   b. increased in-pit rock breaking and handling using mobile equipment;

   c. increased hours for crushing and screen operations;

   d. increased potential for noise and other nuisance;

   e. increased costs for crushing and screening operations and increased electricity usage.

   These burdens are economic and environmental, with the potential to significantly increase Council's impact on the environment and the local community.

5. A reduction in blasting limits will lead to an increased number of blasts undertaken to maintain quarry operations. This is counterproductive as it has the potential to exacerbate environmental and community adverse impacts.

6. Geotechnical experience on-site would indicate that Council would not be able to fully comply with the reduced limits proposed by DEHP. Council endeavours to plan its blast design to achieve a net 5mm/s ground vibration peak particle velocity where practicable.

7. The quarry pit and mine planning over recent decades has been developed around current approved licence conditions and retrospective mine development is unreasonable and impractical.

Whilst Council cannot agree to voluntarily reducing existing environmental limits we reassure the Department that Council is committed to minimising our environmental and community impact. Council has provided extensive information to the Department of Natural Resources and Mines regarding our proactive and ongoing commitment to improving blasting operations at Mt Coot-tha Quarry.

Community consultation

As discussed above, Council has been liaising and disseminating detailed information about the quarry, its operations and lifespan to the local community for more than 10 years.

Council currently notifies by email about 80 affected residents approximately 48 hours prior to any blast. Included in the mail-out are "groups". In fact, there used to be a community consultation group between the quarry and the resident representatives but this went into recess at the request of the resident's chairman.

Council finds email notification administratively efficient, and has generally received support for this approach from the relevant residents. In this regard, it should be noted that only a small minority of residents would like notification via multiple technologies.

All residents are invited to attend Lord Mayor and Civic Cabinet Listens Forums to discuss any concerns residents may have in their local Wards or across Brisbane. Recently two people who live near the quarry attended such a forum. The quarry was discussed.

Council considers its communication strategy works well.

Please do not hesitate to contact me should you require any further information.

Regards

sch4p4(6) Personal Information
[redacted]

Mica Julien
Executive Manager
Field Services Group
Brisbane Infrastructure
Brisbane City Council

BRISBANE CITY
Dedicated to a better Brisbane

Brisbane City Council ABN 72 002 765 795

Manager's Office
Asphalt and Aggregates
228 Curtin Avenue West, Eagle Farm
GPO Box 1434 Brisbane Qld 4001
T 07 317 82090
terry.bird@brisbane.qld.gov.au

10 November, 2017

Mr Andrew Connor
Executive Director
Industry, Development and South QLD Compliance
Department of Environment and Heritage Protection
Via Email: ESComplianceBrisbaneMoreton@ehp.qld.gov.au

Re: Mt Coot-tha Quarry Blasting Activities EPPR00447313

Dear Mr Connor

I refer to the meeting between the Department and Council on 29 August 2017 during which the Department asked Council to once again consider voluntarily reducing blast and vibration limits at its Mt Coot-tha Quarry. For contextual purposes we also refer you to Council's correspondence to the Department dated 30 August 2016.

Council understands that the Department would like reassurance that the structural integrity of buildings adjacent to the quarry will remain intact despite blasting activities. Council understands that one resident has expressed concern that there is no upper limit to Council's allowable blasting vibration which exceeds 10mm/sec. Council accepts and relies upon research that superficial cosmetic damage (such as cracks in plasterboard etc.) may occur to light framed residential structures at levels greater than 75mm/sec. peak particle velocity (PPV).

As discussed, Council is compliant with its environmental authority EPPR00447313. Accordingly, there is no obligation upon Council to agree to amend its approval. By way of background we note the following:

- Mt Coot-tha Quarry is recognised by the Queensland Government as a Key Resource Area known as KRA42 and the boundary and separation areas are identified by the State in its mapping dated October 2013.
- Quarry operations have existed at this site in some form for well over 100 years.
- The quarry pit and mine planning over recent decades has been developed around current approved licence conditions.
- In order for the quarry to be practicable, there are particular operational constraints.
- Nationally and internationally renowned third party experts are retained by Council to design, monitor and provide oversight of the quarrying operations.
- Should the blasting limits be reduced, operations will be changed such that there will be increased environmental impacts, including more blasting over longer periods and much more mechanical rock hammer breaking.

- International Standards like the Australian Standard, the British Standard or the German Standard all indicate levels of vibration that are protective of infrastructure integrity. Appendix J of the Australian Standard AS2187.2-2006, and in particular Table J4.4.2.1 specifies a guide value to prevent cosmetic damage to “unreinforced or light framed structure, residential or light commercial type buildings” as a minimum of 15mm/s for low frequency (4Hz) increasing to 50mm/s for higher frequency component vibration (>40Hz).

Notwithstanding the above, in the interests of assisting the Department in addressing the concerns of one local resident (noting for the sake of clarity, that Council does not accept the basis of those complaints), Council will agree, on an informal basis, that the upper level of permissible vibration not exceed the damage threshold values specified in the Australian Standard (ie. Table J.4.4.2.1), previously mentioned. Council is happy to provide the relevant blasting vibration data to you.

We trust this pledge by Council to not exceed the blast vibration levels detailed in Table J4.4.2.1 (Attached for reference) will reassure any resident who is concerned about upper limits to blast vibration.

Please do not hesitate to contact me should you require any further information.

Regards

sch4p4(6) Personal Information

Terry Bird
Manager
Asphalt and Aggregates
Brisbane Infrastructure
Brisbane City Council

Cc
Matt Karle
Compliance Delivery Manager, South Queensland Compliance – Brisbane Moreton Bay
Environmental Services and Regulation
Department of Environment and Heritage Protection
Matt.Karle@ehp.qld.gov.au

From: Matthew R Goodfellow [matthew.r.goodfellow@tmr.qld.gov.au]
Sent: Wednesday, 4 October 2017 1:58 PM
To: KARLE Matt
CC: Mark S Kanowski
Subject: RE: Mt Coot-tha Quarry
Attachments: RI8507BlastingVibration1989.pdf

Hi Matt,

As discussed, AS2187.2 2006 is a well-recognised standard. In relation to building damage from vibration this standard references other well-recognised publications being the British Standard BS7385.2 and the US Bureau of Mines technical report (8507). It is noted that the British Standard includes frequency dependant damage criteria but also references the US Bureau of Mines technical report and states that:

> *Some data [13] suggests that the probability of damage tends towards zero at 12.5 mm/s peak component particle velocity. This is not inconsistent with an extensive review of the case history information available in the UK.*

It is noted that the Standard states that soil compaction issues may require a lower limit.

The US Bureau of Mines technical report states that a peak particle velocity level of 0.5 in/s (12.7 mm/s) (This assumes a 5-pct probability for very superficial cracking.) is a 'Safe level' of blasting vibrations for residential type structures. The report notes that 'Additional work on fatigue and special soil and foundation types may later justify stricter criteria.' The study also states that newer modern drywall homes may be provided with a higher safe limit 0.75 in/s (19.0 mm/s). This higher level has not been referred to in BS7385.2.

Regards,

Matt

Matthew Goodfellow
Principal Advisor (Noise & Air) | Geospatial, Design & Capability
Engineering & Technology | Department of Transport and Main Roads

Floor 19 / 313 Adelaide Street | Brisbane City Qld 4000
GPO Box 1412 | Brisbane City Qld 4001
P: (07) 3066 8273
E: matthew.r.goodfellow@tmr.qld.gov.au
W: www.tmr.qld.gov.au

From: KARLE Matt [mailto:Matt.Karle@ehp.qld.gov.au]
Sent: Wednesday, 4 October 2017 11:50 AM
To: Matthew R Goodfellow <matthew.r.goodfellow@tmr.qld.gov.au>
Subject: RE: Mt Coot-tha Quarry

Thanks Matthew

I have received the below information. Following our conversation on or about the 27th September 2017, was additional information to be forthcoming?

Regards

Matt Karle
Compliance Delivery Manager, South Queensland Compliance – Brisbane Moreton Bay

Environmental Services and Regulation
Department of Environment and Heritage Protection
P 07 5316 8403
33 King Street, Caboolture Qld 4510

From: Matthew R Goodfellow [mailto:matthew.r.goodfellow@tmr.qld.gov.au]
Sent: Monday, 18 September 2017 2:03 PM
To: KARLE Matt <Matt.Karle@ehp.qld.gov.au>
Cc: Sheng Zhang <Sheng.Z.Zhang@tmr.qld.gov.au>
Subject: FW: Mt Coot-tha Quarry

Hi Matt,

As discussed below is a list of documents that are referenced when considering vibration criteria for blasting.

- Australian and New Zealand Environment Council [ANZEC], (1990). *Technical Basis for Guidelines to Minimise Annoyance Due To Blasting Overpressure and Ground Vibration.*
- Australian Standard: AS 2187.2-1993: *Explosives – Storage, Transport and Use* – Part 2: *Use of explosives*. Standards Australia, Sydney, New South Wales.
- *Environmental Protection Act 1994* Section 440ZB
- Department of Environment and Heritage Protection (DEHP) (2016). *Guideline: Noise and Vibration from Blasting*. Permit and Licence Management, Department of Environment and Heritage Protection, Queensland.

It should be noted that the ANZEC document (Section 1.4) states that the human comfort levels are for guidance only and may be varied. In addition AS2187.2 (Section J4.1 General) notes that the human comfort levels are informative and not intended to override statutory requirements.

The EPAct Section 440ZB is a default noise standard which includes a vibration component. If you haven't already done so please review it in the context of 440Q (2) and Schedule 1 Part 1, section '3 Nuisance regulated by other laws'.

I will call to discuss soon.

Regards,

Matt

Matthew Goodfellow
Principal Advisor (Noise & Air) | Geospatial, Design & Capability
Engineering & Technology | Department of Transport and Main Roads

Floor 19 / 313 Adelaide Street | Brisbane City Qld 4000
GPO Box 1412 | Brisbane City Qld 4001
P: (07) 3066 8237
E: matthew.r.goodfellow@tmr.qld.gov.au
W: www.tmr.qld.gov.au

From: Sheng Zhang
Sent: Wednesday, 6 September 2017 9:47 AM
To: Matthew R Goodfellow <matthew.r.goodfellow@tmr.qld.gov.au>
Subject: FW: Mt Coot-tha Quarry

From: KARLE Matt [mailto:Matt.Karle@ehp.qld.gov.au]
Sent: Friday, 1 September 2017 12:44 PM
To: Sheng Zhang <Sheng.Z.Zhang@tmr.qld.gov.au>; Mark S Kanowski <mark.s.kanowski@tmr.qld.gov.au>
Subject: Mt Coot-tha Quarry

Hi Sheng and Mark

EHP's technical specialist (Antoine David) is currently on sch4p4(6) Personal Information his absence has impacted our technical capabilities with respect to noise and vibration.

I understand that Mark Kanowski recently received and responded to an enquiry from EHP Officer Melanie Scanesin EHP's sunshine coast office. Mark's assistance was much appreciated in that project.

EHP is responding to a long standing concern about vibration from blasting at the Mt Coot-tha Quarry near Brisbane. The concern raised alleges that quarry blasting has impacted residential premises, and in particular one resident who has recently built a new home.

If TMR employs suitably qualified and experienced noise and vibration experts, can TMR you advise whether there is any professional or industry known shortcomings with AS2187.2? Is AS2187.2 and in particular Appendix J a widely used and often referred to Australian Standard, and recognised as an appropriate point of reference in relation to vibration and noise from blasting?

EHP looks forward to your reply on this question.

Regards

Matt Karle
Compliance Delivery Manager, South Queensland Compliance – Brisbane Moreton Bay
Environmental Services and Regulation
Department of Environment and Heritage Protection

P 07 5316 8403
33 King Street, Caboolture Qld 4510

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Structure Response and Damage Produced by Ground Vibration From Surface Mine Blasting

By D. E. Siskind, M. S. Stagg, J. W. Kopp,
and C. H. Dowding

March 3, 1849

UNITED STATES DEPARTMENT
Cecil D. Andrus, Secretary

BUREAU OF MINES
Lindsay D. Norman, Director

US Department of Interior
Office of Surface Mining
Reclamation and Enforcement

Kenneth K. Eltschlager
Mining/Blasting Engineer
3 Parkway Center
Pittsburgh, PA 15220

Phone 412.937.2169
Fax 412.937.3012
Keltschl@osmre.gov

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STRUCTURE RESPONSE AND DAMAGE PRODUCED BY GROUND VIBRATION FROM SURFACE MINE BLASTING

by

D. E. Siskind[1], M.S. Stagg[2], J. W. Kopp[3], and C. H. Dowding[4]

ABSTRACT

The Bureau of Mines studied blast-produced ground vibration from surface mining to assess its damage and annoyance potential, and to determine safe levels and appropriate measurement techniques. Direct measurements were made of ground-vibration-produced structure responses and damage in 76 homes for 219 production blasts. These results were combined with damage data from nine other blasting studies, including the three analyzed previously for Bureau of Mines Bulletin 656.

SAFE ~~Save~~ levels of ground vibration from blasting range from 0.5 to 2.0 in/sec peak particle velocity for residential-type structures. The damage threshold values are functions of the frequencies of the vibration transmitted into the residences and the types of construction. Particularly serious are the low-frequency vibrations that exist in soft foundation materials and/or result from long blast-to-residence distances. These vibrations produce not only structure resonances (4 to 12 Hz for whole structures and 10 to 25 Hz for midwalls) but also excessive levels of displacement and strain.

Threshold damage was defined as the occurrence of cosmetic damage; that is, the most superficial interior cracking of the type that develops in all homes independent of blasting. Homes with plastered interior walls are more susceptible to blast-produced cracking then modern gypsum wallboard; the latter are adequately protected by a minimum particle velocity of approximately 0.75 in/sec for frequencies below 40 Hz.

Structure response amplification factors were measured; typical values were 1.5 for structures as a whole (racking) and 4 for midwalls, at their respective resonance frequencies. For blast vibrations above 40 Hz, all amplification factors for frame residential structures were less than unity.

The human response and annoyance problem from ground vibration is aggravated by wall rattling, secondary noises, and the presence of airblast. Approximately 5 to 10 pct of the neighbors will judge peak particle velocity levels of 0.5 to 0.75 in/sec as "less than acceptable" (i.e., unacceptable) based on direct reactions to the vibration. Even lower levels cause psychological response problems, and thus social, economic, and public relations factors become critical for continued blasting.

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[1] Geophysicist, Twin Cities Research Center, Bureau of Mines, Twin Cities, Minn.
[2] Civil engineer, Twin Cities Research Center, Bureau of Mines, Twin Cities, Minn.
[3] Mining engineer, Twin Cities Research Center, Bureau of Mines, Twin Cities, Minn.
[4] Civil engineer; Professor of Civil Engineering, Northwestern University, Evanston, Ill.

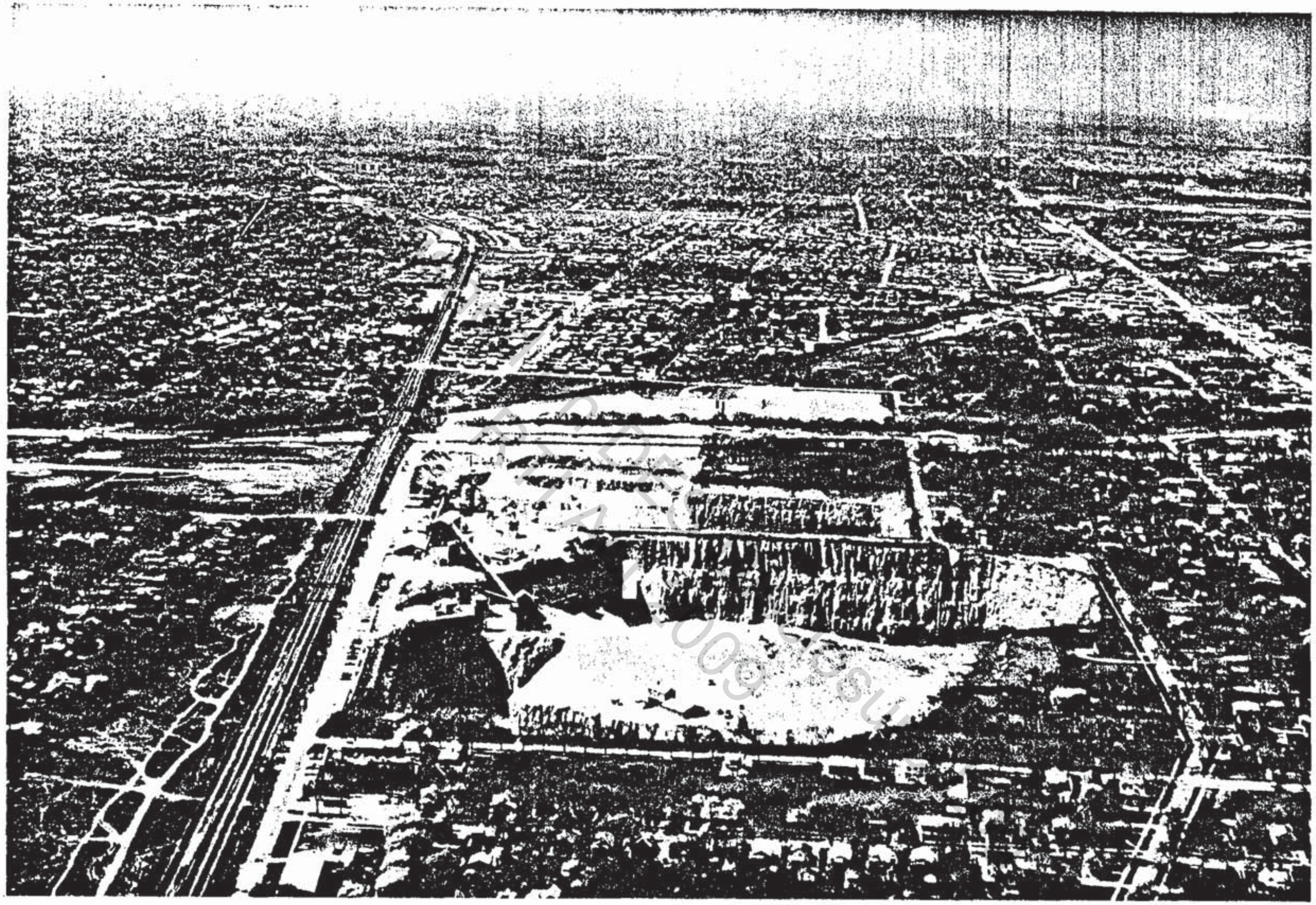

Figure 1.—Occupied residences near operating surface mine.

INTRODUCTION

Gound vibrations from blasting have been a continual problem for the mining industry, the public living near the mining operations, and the regulatory agencies responsible for setting environmental standards. Since 1930, the Bureau of Mines has studied various aspects of ground vibration, airblast, and instrumentation, culminating in Bulletin 656 in 1971(*37*)[5].

In that publication, Nicholls extensively reviewed blast design effects on the generation of vibrations, ground vibration and airblast propagation, and seismic instrumentation. Bulletin 656 established the use of peak particle velocity in place of displacement, a minimum delay interval of 9 msec for scaled distance calculations, and a safe scaled distance design parameter of 50 ft/lb$^{1/2}$ for quarry blasting in the absence of vibration monitoring. The authors also included a damage summary analysis originally published in 1962 by Duvall and Fogelson as Bureau of Mines Report of Investigations 5968 (*14*). New data available since the 1962 report were described in Bulletin 656, but a new analysis to include these data was not performed.

Recommended was the use of peak particle velocity to assess the damage potential of the ground vibrations, and 2.0 in/sec as an overall safe level for residential structures. These recommendations have been widely adopted by the mining and construction industry and incorporated into numerous State and local ordinances that regulate blasting activity. Soon after publication of the 2.0-in/sec safe level criterion, it became apparent that it was not practical to blast at this high vibration level. Many mining operations with nearby neighbors were designing their blasts to keep velocities as low as 0.40 in/sec. Severe house rattling caused fear of property damage below the 2.0-in/sec level, and many homeowners were attributing all cracks to the blast vibrations.

Pennsylvania was the first State to adopt the 2.0-in/sec peak particle velocity criterion as a safe standard in 1957. However, in 1974 it was forced to adopt stricter controls because of citizen pressure and lawsuits involving both annoyance and alleged damage to residences. There existed no technologically based and supportable criteria for mine, quarry, and construction blasting other than the 2.0-in/sec criteria from Bulletin 656 and RI 5968. The general growth of mining, the proximity of mining and quarrying to their residential neighbors, and greater environmental awareness have all required reexamination of blasting regulations and justified further research.

In 1974 the Bureau of Mines began to reanalyze the blast damage problem, expand the Duvall and Fogelson 1962 study, and overcome its more serious shortcomings through the following efforts:

1. Direct measurements were made of structural response, and damage was observed in residences from actual surface-mine production blasting.
2. Damage data from six additional studies, not available in 1962, were combined with three studies analyzed by Duvall and Fogelson, plus the new Bureau of Mines measurements.
3. Probabilistic analysis techniques were used on various sets of data, as well as the conventional statistical derivation of mean square fit and standard deviation for the various damage thresholds.
4. Particular emphasis was placed on the frequency dependence of structure response and damage, recognizing that the response characteristics and frequency content of the vibrations are critical to response levels and damage probabilities.
5. An analysis was made of various studies of human tolerance to vibrations, although most data are from steady-state rather than impulsive sources.

Italic

[5] ~~Underlined~~ numbers in parentheses refer to items in the list of references preceding the appendixes.

An understanding of how houses respond to ground vibration and the vibration characteristics most closely related to this response will enable operators to design blasts to minimize adverse effects. The mining industry needs realistic design levels and also practical techniques to attain these levels. At the same time, environmental control agencies responsible for blasting and explosives need reasonable, appropriate, and technologically established and supportable criteria on which to base their regulations. Finally, neighbors around the mining operations and other blasting, as shown in figure 1, require protection of their property and health so that they do not bear an unreasonable personal cost.

This report summarizes the state of knowledge on damage to residences from surface mine, quarry, and construction blasting. Included are discussions of applicable data on fatigue and human response, although work is continuing in these areas. An analysis was also made on vibration production from mining blasts. The generation and propagation data in Bulletin 656 are for smaller quarry blasts, which are also typically characterized by thin overburden layers.

The damage criteria presented herein were developed to quantify the response of and damage to residential-type structures from small to intermediate-sized blasts as used in mining, quarrying, construction, and excavation. Application of these criteria by regulatory agencies will require an analysis of social and economic costs and benefits for the coexistence of blasting and an enviromentally conscious society.

ACKNOWLEDGMENTS

The authors acknowledge the generous assistance of many regulatory agencies, engineering consultants, powder companies, homeowners, and mine and quarry operators. Special thanks are due to the Pennsylvania Department of Environmental Resources for demonstrating the need for this ground vibration research. Much of the fieldwork and data reduction was done by Virgil J. Stachura, Alvin J. Engler, Steven J. Sampson, Michael P. Sethna, Bryan W. Huber, Eric Porcher, and John P. Podolinski. Valuable technical support was provided by G. Robert Vandenbos for all stages of the blasting research.

GROUND VIBRATION CHARACTERISTICS

Ground vibrations from blasting are an undesirable side product of the use of explosives to fragment rock for mining, quarrying, excavation, and construction. This ground vibration or seismic energy is usually described as a time-varying displacement, velocity, or acceleration of a particular point (particle) in the ground. It can also be measured as various integrated (averaged) energy levels. Three mutually orthogonal time-synchronized components are required to characterize the motion fully. Alternatively, the three components can be combined into a true vector sum for any instant in time or a pseudo vector sum derived from vector addition of the maximums of each component, independent of time (*50*).

The descriptors for motion are related by integration and differentiation:

$$V = \frac{d}{dt} D = \int A dt.$$

$$\text{and } A = \frac{d}{dt} V = \frac{d^2}{dt^2} D$$

where D is displacement, V is velocity, and A is acceleration. When the vibrations can be approximated by a sine wave (simple harmonic motion), the relationships above become:

$$\begin{aligned} D &= D_0 \sin(2\pi ft), \\ V &= D_0 (2\pi ft)\cos(2\pi ft) = V_0\cos(2\pi ft), \\ \text{and } A &= -D_0(2\pi ft)^2\sin(2\pi ft) \\ &= -A_0\sin(2\pi ft). \end{aligned}$$

where f is frequency, t is time, and, D_0, V_0, and A_0 are constants. Peak values correspond to the time when the trigonometric functions equal unity, and the relationships for these peak values then become:

$$\begin{aligned} D_0 &= \frac{V_0}{2\pi f} = \frac{A_0}{(2\pi f)^2} \\ V_0 &= 2\pi f D_0 = \frac{A_0}{2\pi f} \\ \text{and } A_0 &= (2\pi f)^2 D_0 = 2\pi f V_0 \end{aligned}$$

Complex vibrations cannot be approximated by the simple harmonic motion, and either electronic or numeric (computer) integration and differentiation become necessary for conversions.

Interactions between the vibrations and the propagating media give rise to several types of waves, including direct compressional and shear body waves, refracted body waves, and both horizontally and vertically polarized surface waves. These vibrational waves are of primary importance in studies of the earth's interior and earthquake characteristics, but their individual effects have been totally neglected in blasting seismology. Analysis of damage to structures does not require knowledge of what happens between the source and the receiver or of the type of wave. It requires only the vibrational input to the house at its foundation. Additionally, multiply-delayed shots are sufficiently complex vibration sources to make identification of individual waves difficult, if not impossible, under most conditions.

TIME AND FREQUENCY PROPERTIES OF MINING BLASTS

The amplitude, frequencies, and durations of the ground vibrations change as they propagate, because of (a) interactions with various geologic media and structural interfaces, (b) spreading out the wave-train through dispersion, and/or (c) absorption, which is greater for the higher frequencies. Close to the blast the vibration character is affected by factors of blast design and mine geometry, particularly charge weight per delay, delay interval, and to some extent direction of initiation, burden, and spacing (*56*). At large distances the factors of blast design become less critical and the transmitting medium of rock and soil overburden dominate the wave characteristics.

Particle velocity amplitudes are approximately maintained as the seismic energy travels from one material into another (i.e., rock to soil), probably from conservation of energy. However, the vibration frequency and consequently the displacement and acceleration amplitudes depend strongly on the propagating media. Thick soil overburden as well as long absolute (as opposed to scaled) distances create long-duration, low-frequency wave trains. This increases the response and damage potential of nearby structures.

Frequencies below 10 Hz produce large ground displacement and high levels of strain, and also couple very efficiently into structures where typical resonant frequencies are 4 to 12 Hz for the corner or racking motions. Racking is whole-structure distortion with characteristic shear stresses and failures. Previous studies described the frequency character of vibration from quarry (*37*) and coal mine blasts (*56*), and a recent report by Stagg on instrumentation for ground vibration summarized the frequency characteristics of vibrations from small to moderate-sized blast sources (*50*). Ground vibration frequencies from three types of blasts are shown in figure 2, all measured at the closest residence where peak particle velocities were within 0.5 to 2.0 in/sec. Although the shot types in figure 2 are labeled coal mine, quarry, and construction, the frequency-determining factors are the shot sizes, distances, and rock competence. The coal mine and quarry blasts were all more than 200 lb/delay at distances exceeding 350 ft. The construction (and excavation) shots ranged from 1¼ to 12¾ lb at distances of 30 to 160 ft. Soil overburdens were 0 to 5 ft for construction, under 10 ft for quarries, and generally above 5 to 10 ft for coal mines.

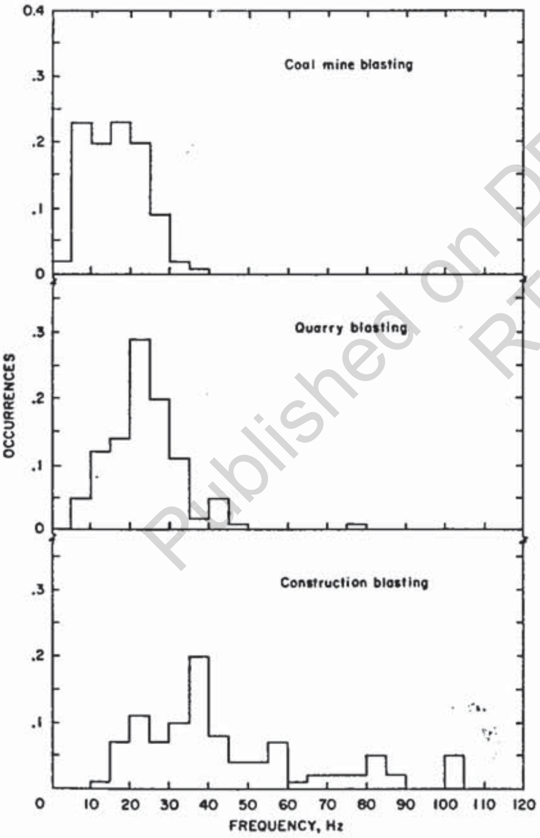

Figure 2.—Predominant frequencies of vibrations from coal mine, quarry, and construction blasting.

Time histories and Fourier frequency amplitude spectra from three typical blasts measured by a buried three-component transducer are shown in figures 3 to 5 (*50*). The coal mine shot is characterized by a trailing large-amplitude, low-frequency wave, which is probably a surface wave generated in the overburden layers. Quarry blasts do not usually show this low-frequency tail for one or more of the following reasons: smaller charge weights, smaller shot to instrument distances, and thinner soil overburdens. The combination of large shots, thick soil and sedimentary rock overburdens, relatively good confinement, and long-range propagation make coal mine blast vibrations potentially more serious than quarry and construction blasts because of their low frequencies. By contrast, coal mine highwall blasts are inefficient generators of airblast (*46*). Hard rock construction and excavation blasts tend to be shorter in duration and contain higher frequency motions than those of either coal mine or quarry.

Frequency characteristics of blast vibrations depend strongly on the geology and blast delay intervals. Except for the short-distance, all-rock case, they are difficult to predict and vary widely. Therefore, it is desirable to obtain complete time histories rather than simple peak values in any sensitive areas. Many examples of continual complaints about severe rattling at levels below 0.5 in/sec are attributable to the low frequencies. Research is continuing on the effects of blast design, face orientation, and near-surface geology on the character of both the ground vibrations and airblast.

OTHER VIBRATION SOURCES

Earthquakes, nuclear blasts, and very large scale, in situ mining shots all produce potentially damaging ground vibrations, as well as do other static and quasistatic vibration sources (traffic, pile driving, sonic booms, etc.). The first Bureau of Mines blast vibration summary in 1942 examined the levels of earthquake vibrations and the corresponding Mercalli intensities for damage, and concluded these did not apply to blasting (*51*). Earthquakes produce long-duration and very low frequency events.

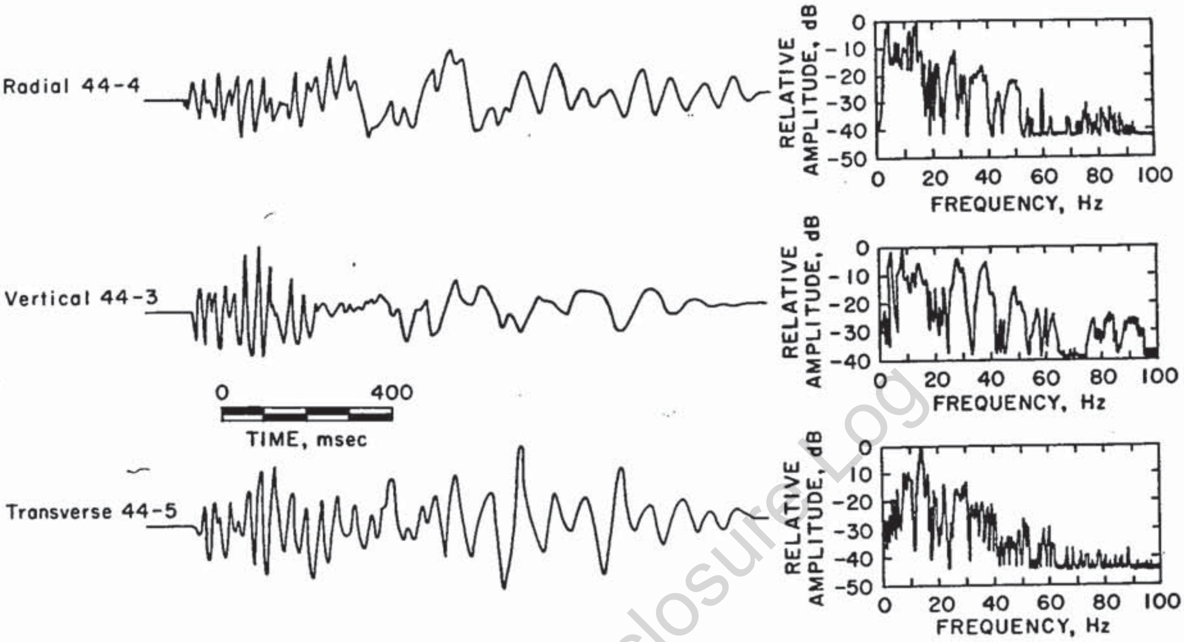

Figure 3.—Coal mine blast time histories and spectra measured at 2,287 ft.

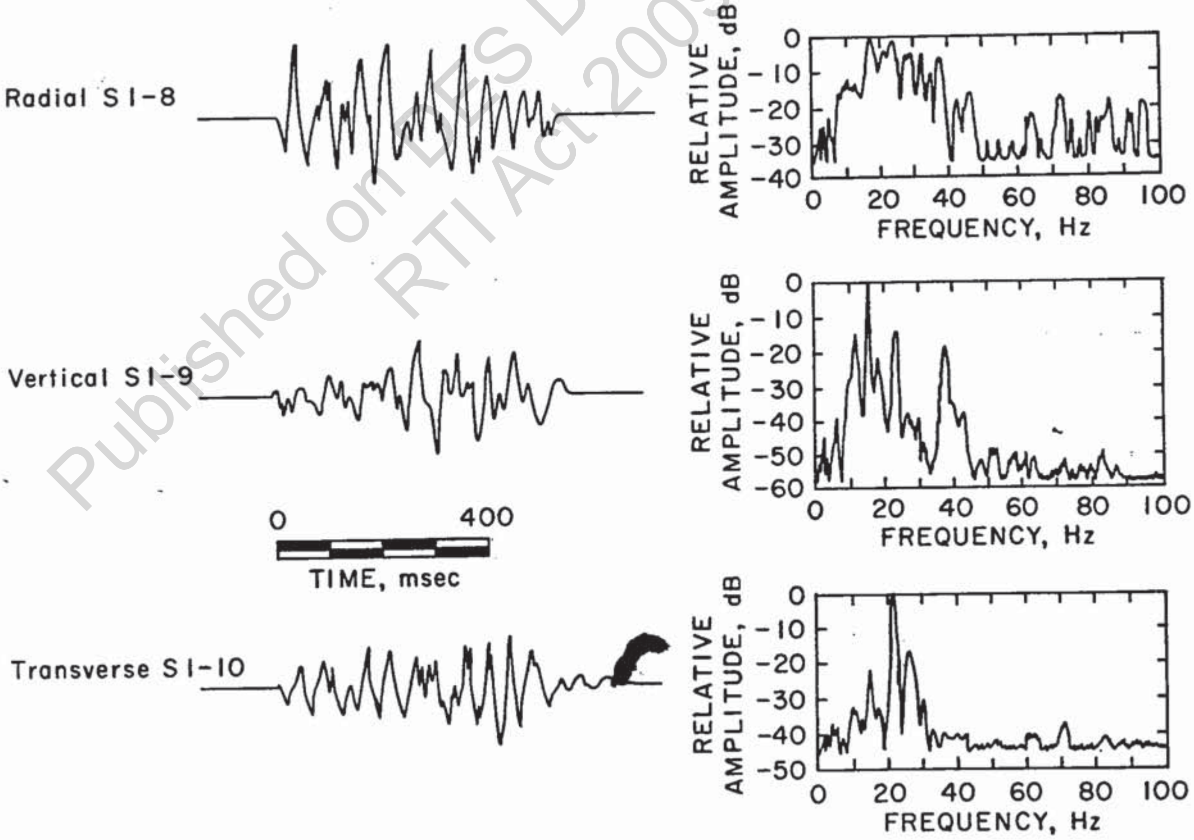

Figure 4.—Quarry blast time histories and spectra measured at 540 ft.

Acceleration levels are typically used by seismologists to quantify damage potential. These may be of moderate and even lower levels than found in blasting; however, their low frequencies produce large particle velocities and enormous displacements. As an example, Richter states that a 0.1 g acceleration at 1 Hz is ordinarily considered damaging in earthquake seismology (*41*). The corresponding particle velocity and displacement are 6.15 in/sec and 0.98 in, respectively, assuming simple harmonic motion. The same acceleration at 20 Hz would only produce 0.308 in/sec particle velocity and 0.0025 in displacement. Richter also observes that the damage potential of a given vibration is dependent on its duration, with 0.1 g at 1 Hz likely not to produce damage for events of a few seconds, but very serious for earthquake-type events of 25 to 30 sec (*41*).

A similar case is provided by the Salmon nuclear study and similar large blasts (*5, 35, 39, 42-43, 45*). These blasts all produced low-frequency and long-duration ground vibrations resulting from their sizes and distances. The Salmon vibration time history was 90 sec long at the structures (18 to 31 km) that were alleged to have been damaged. These durations are hardly comparable to those in mine, quarry, and construction blasting. Consequently, damage data of this kind cannot justifiably be correlated with the scale of blasting of concern in this analysis. However, the dynamic modeling techniques developed during the extensive research of earthquake and nuclear blast response can be applied to the study of blasting and the mechanisms of structural response.

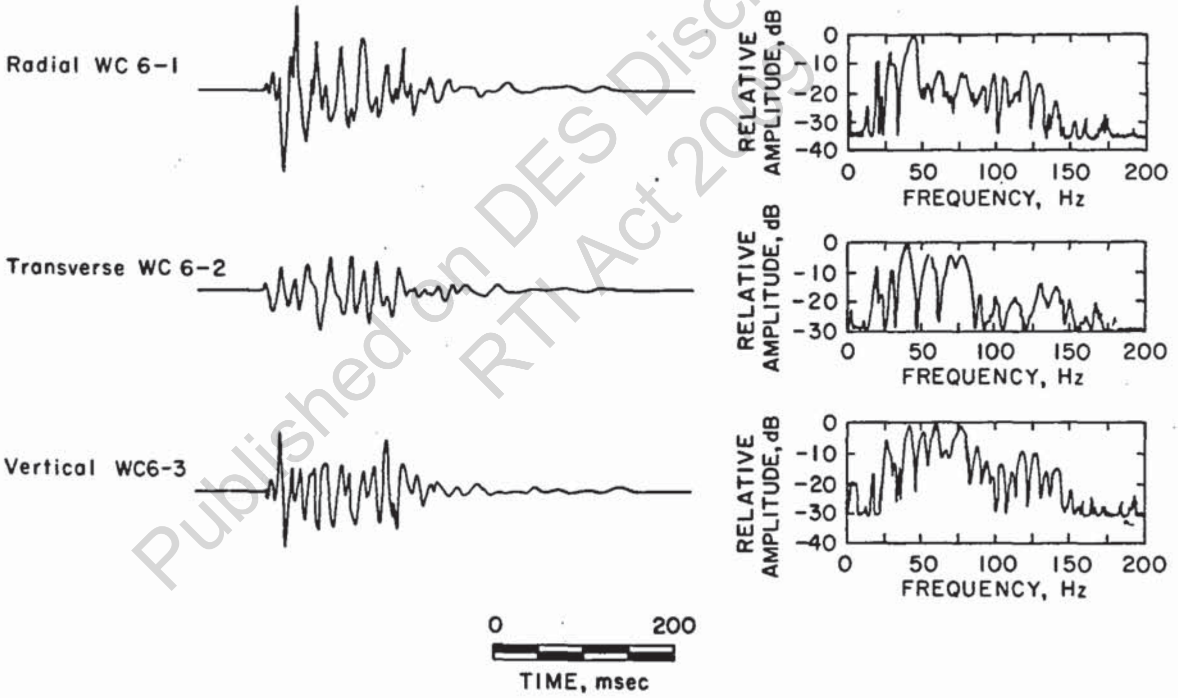

Figure 5.—Construction blast time histories and spectra measured at 75 ft.

GENERATION AND PROPAGATION

Much research has been conducted on ground vibrations. Generation and propagation of ground vibrations have been studied extensively to determine the effects of blast design and geology on vibration amplitudes and frequency character. In Bulletin 656, Nicholls summarized the Bureau's investigation of vibrations produced by blasting in 25 stone quarries, dating back to 1959 (*37*). The Bureau also conducted a series of studies of vibrations generated in four operating underground metal mines in 1974 (*45*). A major study was recently completed by Wiss that quantifies the influence of many of the blast design parameters on both ground vibration and airblast generation and propagation in five surface coal mines (*56*). Lucole also recently published the results of a year of routine monitoring of vibration levels generated by various types of blasting (*29*).

Prior to the last two studies, no data existed on vibrations generated by blasting in surface coal mines. It has been standard practice to apply the blast design rules developed for the small-hole, hard-rock quarry blasting to surface coal mines. Blast holes in surface coal mines have typical diameters exceeding 6 in, and in large area mines they are typically 9 to 15 in. These diameters are larger than those used in most quarries. The highwall blasts of surface coal mines are heavily confined, since they are used only to loosen the overburden and produce little or no throw. Decking is often used with complex timing systems, combining electronic and pyrotechnic delays. The rock being blasted is highly layered and of lower sonic velocity and strength than that in aggregate and lime quarries. Distances to houses are usually greater than for quarries, which are often in or near urban centers. Soil and incompetent rock overburden beneath structures near coal mines is normally tens of feet thick, far more than at most quarries.

Consequently, coal mine blasting is normally characterized as follows:

1. Relatively large charge weights per delay.
2. Complex delay systems that are optimized for efficient fragmentation but that may produce adverse ground vibration frequencies.
3. Relatively high ground vibration levels close-in from heavy confinement of highwall shots.
4. Relatively rapid falloff of ground vibration levels with distance because of attenuation in weak rock.
5. Ground vibrations having predominantly low frequencies because of thick soil overburdens, strong geologic layering that favors surface waves, and large blast-to-structure distances.

BLAST DESIGN AND GROUND VIBRATION GENERATION

As in studies on quarry blasting, most blast design parameters for surface coal mine blasts have little influence on the generated vibrations. Charge weights per delay were again the most influential parameter. A small decrease in ground vibrations was noted for shallow as opposed to great depths of burial. Also, the location of the receiver relative to both the face and direction of blast initiation influenced the delay intervals at which constructive wave interference was experienced (*56*).

The Bureau of Mines vibration data are given in table 1. Included are charge weights, distances, ground vibration, and structure vibration levels for the predominantly coal mine blasts. The two horizontal components of motion were alined with the walls of the nearby structures for analysis of response and did not necessarily correspond to the traditional "radial" and "transverse." The "structure number" of table 1 is for identification, and the "structure type" is the number of stories.

Vibration levels generated from one surface coal mine are shown in figure 6. The maximum horizontal and vertical ground motions were plotted for each blast. Equations and statistics for the various vibration propagations, including Site A (fig. 6), are given in table 2. All particle velocities are in inches per second, distances in feet, and charge weights in pounds. Propagation curves from a variety of surface coal mines are given in figures 7–9. Six of the propagation curves (Nos. 1–2 and 6–9) are from vertical hole blasts studied by Wiss (*56*). The remaining propagation curve (No. 19) is from a single Bureau of Mines site, where actual radial and transverse values were available.

Table 1.—Production blasts and ground vibration measurements

Shot	Facility	Shot type	Total charge, lb	lb per delay	Sealed distance, ft/lb$^{1/2}$	Peak ground vibration, in/sec			Peak structure motion, in/sec							Structure number (table 3)	Structure type
									Low corner			High corner		Midwall			
						H_1	H_2	V	H_1	H_2	V	H_1	H_2	H_1	H_2		
1	Coal	Highwall ---	6,000	500	38.00	1.07	1.07	0.80				0.76	0.49		1.41	27	1
2	Coal	---- do ------	7,200	600	33.00	1.38	1.19	.68				.87	.75		1.57	27	1
3	Coal	---- do ------	7,800	650	29.00	1.89	1.74	.59				.79	.54		1.55	27	1
4	Coal	---- do ------	7,200	1,200	20.00	1.91	1.85	.95				.81	.67		2.19	27	1
5	Coal	---- do ------	7,800	1,300	18.10	2.07	2.33	.94				.87	.56	2.37	3.18	27	1
6	Coal	---- do ------	7,800	650	24.00	3.73	1.73	.73				.82	.60	2.79	2.83	27	1
7	Coal	---- do ------	7,800	650	23.00	5.31	3.82	1.04				1.29	.70	4.96	1.55	27	1
9	Coal	---- do ------	6,600	550	22.00	2.34	1.97	.88				.82	.42	2.63	1.67	27	1
10	Coal	---- do ------	5,400	450	26.00	1.20	1.22	.61				.76	.39	1.24	1.72	27	1
11	Coal	---- do ------	3,600	300	33.00	.72	.52	.28				.33	.24	.82	.60	27	1
13	Quarry	Highwall ---	2,033	280	24.00	.76	.66	.49						1.02		1	1
14	Quarry	---- do ------	4,353	218	61.00	.29	.22	.32	0.90		0.85					1	1
15	Quarry	---- do ------	1,995	303	52.00	.18	.22	.36						.11		2	1
16	Quarry	---- do ------	2,850	187	88.00	.49	.24	.26						.37		3	2
17	Quarry	---- do ------	5,047	200	100.00	.21		.14						.33		1	1
17	Quarry	---- do ------	5,047	200	129.00	.16								.15		4	2
18	Quarry	---- do ------	2,367	305	22.90	1.00		3.82						1.53		1	1
18	Quarry	---- do ------	2,367	305	45.70	.53								.30		4	2
19	Quarry	---- do ------	2,450	160	86.00	.44		.33						.26		5	2
19	Quarry	---- do ------	2,450	160	119.00	.50								.32		6	1
33	Quarry	---- do ------	8,762	700	124.70	.15	.13	.07						.30		7	1
33	Quarry	---- do ------	8,762	700	124.70	.05								.16		8	1
35	Iron	Highwall ---		4.200	17.90		1.86								1.74.	10	2
35	Iron	---- do ------		4,200	17.90	.07		.09						.45		11	2
35	Iron	---- do ------		4,200	17.90	.07		.09						.33		12	2
35	Iron	---- do ------		4,200	17.90	.07		.09						.14		13	1
36	Iron	---- do ------		21,000	132.50	.02		.01						.04		14	2
36	Iron	---- do ------				.02		.01						.06		15	1
36	Iron	---- do ------		21,000	48.30	.03								.05		16	1
37	Iron	---- do ------		2,184	85.60	.18								.38		18	1
38	Iron	---- do ------		15,530	337.80	.01		.01	.01	0.01				.02		14	2
39	Coal	---- do ------	20,300	2,300	64.00	.25	.23	.12	.42	.11	.30			.46	.97	19	2
40	Coal	Parting -----	648	72	767.00	.01	.01	.01							.04	19	2
41	Coal	Highwall ---	21,800	2,600	58.00	.28	.20	.15	.40	.24	.24			.44	.79	19	2
43	Coal	---- do ------	20,700	2,600	56.00	.30	.39	.26	.34	.14	.34			.54	1.49	19	2
43	Coal	---- do ------	20,700	2,600	43.95	.87								1.37		20	1
44	Coal	---- do ------	20,600	2,300	57.00	.21	.36	.28	.29	.10	.42			.45	1.71	19	2
44	Coal	---- do ------	20,600	2,300	47.69	.91								1.20		20	1
45	Coal	Highwall ---	20,700	2,300	55.00	.33	.41	.20	.32	.10	.35			.68	2.27	19	2
45	Coal	---- do ------	20,700	2,300	48.94	1.13								.73		20	1
46	Coal	Ditch --------	3,600	600	91.00	.07	.11	.03	.05	.03	.14			.10	.84	19	2
46	Coal	---- do ------	36,000	600	71.57	.06								.23		20	1
47	Coal	Highwall ---	21,600	2,600	50.00	.26	.29	.24	.25	.10	.71			.54	1.09	19	2
47	Coal	---- do ------	21,600	2,600	47.32	1.10								.93		20	1
48	Coal	---- do ------	20,600	2,300	51.00	.24	.33	.25.	19	.10	.80			.48	1.00	19	2
48	Coal	---- do ------	20,600	2,300	51.71	.79								.68		20	1
49	Coal	---- do ------	19,800	2,200	54.00	.39	.28	.22	.28	.19	.29	.61	.35	1.07		20	1
50	Coal	---- do ------	19,700	2,200	56.00	.24	.15	.25	.22	.17	.36	.40	.28	.87		20	1
51	Coal	---- do ------	19,300	2,200	57.00	.13	.14	.13	.11	.08	.21	.26	.13	.67	.32	20	1
53	Coal	Parting -----	264	24	621.00	.01	.01	.01	.00	.01	.01	.01	.01	.05		20	1
54	Coal	---- do ------	360	36	425.00	.02	.02	.01	.01		.01	.03		.02		20	1
55	Coal	Highwall ---	18,400	2,100	60.00	.14	.13	.18	.13		.30	.21		.51	.36	20	1

56	Coal	---- do ------	17,700	2,000	64.00	.16	.08	.15	.08	.23	.16	.26		.51		20	1
57	Coal	---- do ------	6,000	2,000	65.00	.18	.08	.12			.18	.21		.18	.27	20	1
58	Coal	Parting -----	480	30	444.00	.02	.01	.01			.02	.05		.02	.04	20	1
59	Coal	---- do ------	294	30	788.00	.01	.01	.01			.01	.01	.01	.01	.06	19	2
60	Coal	Highwall ---	21,400	2,000	38.00	.49	.82	.88			.98	.31	.20	.52	1.12	19	2
61	Coal	---- do ------	24,700	2,100	35.00	.44	.90	.93		.65	.93	.42	.30	.67	2.51	19	2
62	Coal	Sweetner ---	1,500	150	138.00	.12	.20	.06		.23	.09	.12	.06	.23	.43	19	2
64	Coal	Highwall ---	24,600	2,100	33.00	.51	.62	.85		.51	.96	.43	.26		1.02	19	2
65	Coal	---- do ------	15,700	2,200	30.00	.45	.59	1.06		.47	1.06	.76	.26		1.33	19	2
66	Coal	---- do ------	15,800	1,900	31.00	.62	.77	1.53		.54	1.56		.30		1.45	19	2
67	Coal	---- do ------	13,540	1,900	29.00	.66	.81	.78		.59	.89	.25	.30		1.92	19	2
68	Coal	Parting -----	300	30	713.00	.01	.01	.01		.01					.07	19	2
69	Coal	Highwall ---	11,040	2,000	26.00	.53	.70	.94		.45		.29	.26		1.76	19	2
70	Coal	Sweetner ---	2,100	300	86.00	.19	.16	.07		.11	.10	.12	.04		.49	19	2
71	Coal	Hilltop ------	9,020	410	67.00	.21	.28	.17		.27	.26	.17	.10		.91	19	2
72	Coal	Ditch --------	3,060	510	93.00	.07	.09	.03		.03	.07	.07			.60	19	2
73	Coal	Highwall ---	19,600	2,000	24.00	1.24	1.24	2.24	.78	.97	2.22	.44	.33	2.08	2.77	19	2
74	Coal	---- do ------	17,100	2,000	23.00	.75	1.12	1.23	.62	.78	1.28	.38	.27	1.06	2.20	19	2
75	Coal	Ditch --------				.09	.07	.08	.07	.06	.14	.05	.05	.18	.35	19	2
76	Coal	---- do ------	3,360	280	93.00	.08	.12	.12			.18	.07	.08	.29	.50	19	2
77	Coal	---- do ------	1,200	220	102.00	.07	.07	.05			.08	.05	.03	.16	.36	19	2
78	Coal	Highwall ---	22,200	2,100	20.00	.68	1.14	1.58			1.79	.50	.39	1.66	2.38	19	2
79	Coal	---- do ------	24,900	2,200	18.20	1.58	1.69	2.45			2.93	.87	.71	2.55	3.24	19	2
80	Coal	Highwall ---	25,100	2,300	16.70	1.14	1.03	0.70			1.04	.63	.54	1.09	2.38	19	2
81	Coal	Sweetner ---	3,240	360	37.00	.35	.45	.24			.35	.25	.21	1.08	1.79	19	2
82	Coal	Hilltop ------	27,000	1,000	22.00	1.98	1.85	1.65			4.01	1.34	.84	3.26		19	2
83	Coal	Ditch --------	2,040	340	81.00	.06	.06	.05						.06	.12	19	2
84	Coal	Highwall ---	25,600	2,200	16.10	1.37	1.05	1.48			2.33	.87	.54	2.96	2.50	19	2
85	Coal	---- do ------	25,400	2,200	15.60	2.20	1.27	1.91			1.15	.87	.58	3.76	3.76	19	2
86	Coal	---- do ------	25,900	2,200	15.30	1.89	1.23	2.21			3.08	.95	.40	3.66	3.04	19	2
87	Coal	Ditch --------	1,320	220	98.00	.08	.05	.06			.07	.05	.03	.24	.30	19	2
89	Coal	Parting -----	360	36	372.00	.01	.01	.01			.02	.02	.02	.03	.04	19	2
90	Coal	Highwall ---	25,500	2,200	15.40	1.68	1.53	2.51			3.37	.94	.51	2.72	3.23	19	2
91	Coal	---- do ------	31,500	2,200	15.70	1.99	1.60	2.45			2.69	.74	.41	2.92	3.67	19	2
92	Coal	Ditch --------				.16	.12	.11			.19	.08	.04	.44	.62	19	2
93	Coal	Parting -----	114	12	626.00	.00	.01	.00						.02	.02	19	2
94	Coal	Highwall ---	30,700	2,200	17.10	.79	1.25	1.41			2.75	.63	.57	2.88	1.73	19	2
95	Coal	---- do ------	26,600	2,200	17.90	2.08	1.14	1.35			2.06	.63	.49	5.07	1.83	19	2
96	Coal	---- do ------	20,500	2,000	19.30	1.22	1.18	.99			2.41	.73	.49	3.07	1.66	19	2
97	Coal	---- do ------		450	118.00	.03	.01	.04	.06	.02				.11		21	1
98	Coal	---- do ------	14,400	450	127.00	.05	.01	.04	.04	.04				.16		21	1
99	Coal	Parting -----	20,880	773	50.00	.27	.19	.15	.34	.26				.61		21	1
100	Coal	---- do ------	18,000	200	53.00	1.26	.88	.72	.46	.59				1.68		21	1
101	Coal	---- do ------	17,500	350	96.00	.08	.05	.08	.13	.05				.29		21	1
102	Coal	---- do ------	27,040	208	48.00	1.20	.79		.69	.58				2.50		21	1
103	Quarry	Highwall ---	4,956	632	62.00	.32	.27	.19				.15	.14	.41	.28	22	2
103	Quarry	---- do ------	4,956	632	28.00	.82	.76	.53			.67	.49	.58	.90		23	1
104	Quarry	---- do ------	5,752	632	59.00	.22	.41	.13	.47	.22		.40	.24	.55	.62	22	2
104	Quarry	---- do ------	5,752	632	26.00	1.09	.77	.44			.60	1.04	.70	1.32		23	1
105	Quarry	---- do ------	4,350	615	22.00	.85	.61	.42			.70	.47	.52	.72		23	1
106	Quarry	---- do ------	17,604	852	144.00	.16	.19	.14	.12	.13		.26	.15	.44	.34	23	1
106	Quarry	---- do ------	17,604	852	79.00	.04	.03	.03	.03	.03		.03	.04	.08	.10	22	2
107	Coal	---- do ------				.17	.26	.20	.13	.26	.29			.53	.42	.26	1
108	Coal	---- do ------				.21	.20	.24	.21	.17	.20	.37	.22	.99	.92	28	1
109	Coal	---- do ------		300	105.00	.09	.04	.08	.08	.15		.11	.32	.30	.31	29	2
110	Coal	Parting -----	21,600	240	52.00	1.33	1.02	.52		.50		.33	.35	1.85	1.49	21	1
111	Coal	---- do ------		320	56.00	.79	.69	.34	.60	.28	.26	.57	.57	1.54	.80	21	1
112	Coal	Highwall ---		300	81.00	.43	.39	.20					.28	.93	1.02	30	1
113	Coal	Parting -----		320	61.00	.45	.69	.33			[illegible]			.86		21	1
114	Coal	---- do ------	23,680	370	68.00	.47	.51	.47			.26			.93	.17	21	1
116	Coal	Highwall ---	12,000	300	38.00	.24	.22	.23	.29	.25	.24	.37	.42	.53	.48	31	1
117	Coal	Parting -----	14,400	360	158.00	.04	.02	.02						.07	.02	21	1

Additional Info. in ERRATA

Table 1.—Production blasts and ground vibration measurements—Continued

Shot	Facility	Shot type	Total charge, lb	lb per delay	Scaled ~~Sealed~~ distance, ft/lb$^{1/2}$	Peak ground vibration, in/sec			Peak structure motion, in/sec							Structure number (table 3)	Structure type
									Low corner			High corner		Midwall			
						H_1	H_2	V	H_1	H_2	V	H_1	H_2	H_1	H_2		
119	Quarry	Highwall	16,608	782	154.00	0.03	0.04					0.04	0.04	0.04	0.11	32	2
120	Coal	do	15,120	120	137.00	.19	.09	0.11	0.25	0.09	0.18					31	2
122	Coal	do		15	430.00	.03	.05	.03	.02	.02	.02	.09	.13	.17	.27	28	1
124	Coal	Parting	1,340	20	447.00	.02	.02	.02	.03	.09	.05	.04				33	2
125	Coal	Highwall	10,200	200	141.00	.13	.13	.21	.09	.09	.01	.16		.72	.32	33	2
126	Coal	Parting	1,200	20	391.00	.02	.02	.03	.01	.02	.02					34	1
127	Coal	Highwall	12,000	400	88.00	.16	.13	.08	.15	.11	.16			.34	.36	34	1
129	Coal	do	15,000	350	166.00	.06	.09	.04	.06	.05	.06			.36	.30	35	1
130	Coal	Parting	890	20	391.00	.02	.02	.01	.05	.04	.07			.04	.05	34	1
131	Coal	Highwall	10,800	400	88.00	.15	.14	.10	.11	.10	.20			.36	.24	34	1
132	Coal	Parting	1,300	30	219.00	.05	.06	.04	.04	.03	.03	.09	.09	.24	.13	33	2
133	Coal	Highwall	24,000	400	60.00	.07	.07	.04	.07	.05	.05		.15	.12	.09	33	2
134	Coal	Parting	2,300	400	60.00	.23	~~.36~~ .32	.16	.22	.19	.12	.32	.23		.49	33	2
135	Coal	------------				1.14	1.00	.02	.76	.66	.75	.61	.75	1.52	2.41	21	1
136	Coal	Parting	29,700	900	16.70	1.54	1.12	1.59	.94	.65		.70	.56	2.07	1.84	21	1
137	Coal	do	2,300	20	447.00	.03	.04	.02	.02	.02	.01	.03	.02	.20	.00	33	2
138	Coal	do	2,300	20	447.00	.03	.04	.02	.01	.01	.01	.05	.02	.20	.04	33	2
139	Coal	Highwall	19,200	400	100.00	.10	.12	.06	.11	.09	.07	.15	.12	.51	.20	33	2
140	Coal	Parting	1,000	20	783.00	.00	.01	.00	.04	.04	.02	.06	.03	.06	.05	35	1
141	Coal	do	1,000	20	537.00	.00	.00	.00		.00				.02		36	1
142	Coal	do	1,000	20	537.00	.00	.00	.00		.01				.02		36	1
143	Coal	Highwall	40,000	400	120.00	.06	.03	.02		.07	.03			.14	.17	36	1
144	Coal	Parting	2,400	10	750.00	.00	.00	.01		.00	.00			.02	.01	36	1
145	Coal	Highwall	40,000	400	120.00	.05	.05	.04	.03	.06	.05			.10	.19	36	1
146	Iron	do		4,580	86.00	.13	.22	.09	.13					.40		37	2
146	Iron	do		4,580	86.00	.05	.05	.04		.04				.08			2
146	Iron	do		4,580	86.00	.13	.22	.09	.42	.20				.50	.67		1
147	Iron	Highwall		8,800	74.00	.15	.17	.04	.15	.15	.03			.27	.22		1
147	Iron	do		8,800	74.00	.15	.17	.04	.39	.28				.70	.62	38	2
147	Iron	do		8,800	74.00	.15	.17	.04	.17	.11	.06			.14	.16	39	1
148	Iron	do		8,230	74.00	.11	.11	.03	.12	.12	.03		.14		.19	38	2
148	Iron	do		8,230	74.00		.11	.04	.11	.10	.03			.18			2
149	Iron	do	58,000	2,500	221.00	.00	.03	.00	.03	.01	.01	.04	.02	.05	.04	41	2
150	Iron	do		3,260	102.00	.07	.11	.07	.03	.04	.02	.07	.04	.16	.14	37	2
151	Coal	do					.02	.01	.03	.01	.01	.03	.05	.07	.05	42	2
152	Coal	do	3,585	255	132.00		.05	.05	.05	.04	.06	.07	.08	.11	.14	42	2
153	Coal	do	3,783	152	171.00		.09	.04	.09	.10	.06	.11	.15	.18	.25	42	2
154	Coal	do	3,000	125	51.00		.34	.51	.55	.38	.79	.44		.98	1.26	43	2
157	Coal	do	4,500	75	127.00		.14		.14	.11					.31		2
157	Coal	do	4,500	75	52.00	.34	.44	.26	.33	.38				.48	.58		1
158	Coal	do	2,450	41	180.00		.10		.10	.09				.25		45	2
158	Coal	do	2,450	41	56.00	.41	.32	.25	.52	.45				.66	.61		1
159	Coal	do	920	23	250.00		.04		.05	.03				.13		45	2
159	Coal	do	920	23	52.00	.33	.24	.33	.27	.25				.57	.46		1
160	Coal	do	5,460	78	51.00	.29	.23	.13	.11	.12		.17		.33	.55	47	1
161	Coal	do	3,280	41	34.00	1.17	.64	.64	.52	.37	.66	.62		2.02	1.72	48	2
162	Coal	do	13,040	602	61.00	.18	.19	.16	.12	.16				.41		49	2
163	Iron	do		8,530	6.50	.73	.53	.85	.81	.99	.87	.96	.61		1.15	50	1
164	Coal	do	3,510	351	45.00	.19	.15	.10	.16	.12	.19		.20	.37	.21	49	2
165	Coal	do	4,914	351	44.00	.25	.36	.13	.26		.25	.41	.48	.76	.64	49	2
166	Coal	do				.18	.17	.20	.13	.17	.19	.20	.23	.28	.32	49	2
167	Coal	do	1,750	35	51.00	.33	.42	.50	.38	.43	.49	.23	.44	.86	.94	51	2
168	Coal	do	4,300	86	27.00	.85	1.16	.72	.98	1.29	.77	.26	1.03	2.51	3.12	51	2

169	Coal	---- do ------	4,300	86	19.20	2.11	1.81	1.45	1.92	1.34	1.27		1.86	6.50	5.10	51	2
170	Coal	---- do ------	4,300	86	16.20	2.84	1.85	1.65	1.72	1.27	1.63	1.01	1.63	3.64	3.71	51	2
171	Coal	---- do ------	1,775	71	17.80	1.23	1.24	.97	.43	.62	.72	.82	.47	2.36	.79	51	2
172	Coal	---- do ------				.20	.17	.21	.19	.26	.29			1.04	.62	49	2
174	Coal	---- do ------	4,300	86	21.00	1.38	1.86	.85	.67	1.15	1.90	1.20	2.06	3.84	2.91	51	2
175	Coal	---- do ------	5,150	212	9.90	10.21	6.92	5.65	3.18	4.02	3.19	3.89	4.09	6.99	10.27	51	2
178	Coal	---- do ------	1,320	33	45.00	1.04	.64	.83	.33	.30	.64					51	2
179	Coal	---- do ------	2,145	33	31.00	1.84	2.08	1.47	1.38	1.32	1.78					51	2
180	Coal	---- do ------	1,620	18	4.00	10.58	2.02	2.92	3.69	1.33	2.12					51	2
181	Coal	---- do ------	1,980	22	18.50	7.25	4.90	4.76	1.65	2.55	2.75					51	2
182	Coal	---- do ------	1,620	18	3.30	6.37	3.46	3.46	3.06	2.60	2.70					51	2
183	Coal	---- do ------	2,375	125	206.00	.02	.02	.02	.02	.02				.16		52	1
186	Coal	---- do ------	350	35	127.00	.06	.04	.03	.05	.03						54	1
187	Coal	---- do ------	350	35	127.00	.04	.04	.04	.06	.03						54	1
189	Coal	Highwall ---	360	40	119.00	.05	.03	.07	.04	.01					.06	54	1
190	Coal	---- do ------	720	40	119.00	.06	.03	.03	.06					.22	.04	54	1
191	Coal	---- do ------	400	40	119.00	.04	.02	.06						.06	.07	54	1
192	Coal	---- do ------	960	40	119.00	.06	.03	.05						.18	.07	54	1
193	Coal	---- do ------	3,780	60	36.00	2.67	2.11	3.20	.81	.72				.72		55	2
194	Coal	---- do ------	320	40	174.00	.02	.02	.02				.01		.07		56	2
195	Coal	---- do ------	424	40	174.00	.02	.01	.02				.01		.08		56	2
196	Coal	---- do ------	680	40	174.00	.03	.02	.03	.02			.02		.12		56	2
197	Coal	---- do ------	4,160	80	38.60	.80	.94	.59								49	2
198	Coal	---- do ------	1,200	30	32.90	1.02	.92	.43								57	1
199	Coal	---- do ------	1,200	30	31.00	1.08	.98	1.20								57	1
200	Coal	---- do ------	5,510	276	66.20	.25	.35	.25								49	2
201	Coal	---- do ------	1,200	30	28.70	1.19	1.13	.77								57	1
202	Coal	---- do ------	1,200	30	25.00	2.06	1.13	1.29								57	1
203	Coal	---- do ------		100	24.70	1.35	.77	.58								58	1
204	Coal	---- do ------		100	24.20	2.23	.68	.65								58	1
205	Coal	---- do ------		100	24.20	1.05	.66	.39	.85		1.00				.43	58	1
206	Coal	---- do ------	1,800	100	24.50	.73	.75	.55		.75				.87		58	1
207	Coal	---- do ------	1,800	100	24.50	1.88	1.76	.49		1.02	.50			.76		58	1
208	Coal	---- do ------		80	19.00	1.45	1.38	1.92								58	1
W 1	Constr	Excavation .	80	6	65.30	.18	.21	.26				.04	.06	.31	.27	59	1
W 2	Constr	---- do ------	14	2	45.40	.49	.58	.67	.44	.04		.28	.12	.92		60	2
W 3	Constr	---- do ------	12	1	60.00	.05	.03	.03	.02				.01	.02		60	2
W 4	Constr	---- do ------	110	7	60.50	.68	.60	.77	.39	.69	.36	.18	.29	.45		61	1
W 5	Constr	---- do ------	110	7	20.80	1.94	2.03	2.23			1.84	.57	.47			61	1
W 6	Constr	---- do ------	32	6	30.60	.35	.19	.29		.31	.27	.09	.18		.28	62	2
W 7	Constr	---- do ------	120	12	46.20	.24	.23	.10	.23	.21	.14	.15	.09	.47	.64	63	2
W 8	Constr	---- do ------	100	6	49.00	.27	.27	.13	.19	.13	[illegible]	[illegible]	.06	.39	.37	63	2
W 9	Constr	---- do ------	1	1	49.20	.04	.06	.08		.07	.05	.05	.03	.20	.26	64	2
W 10	Constr	---- do ------	4	1	30.00	.11	.10	.22	.22	.21	.20	.12	.06	.38	.32	64	2
W 11	Constr	---- do ------	18	4	98.90	.37	.32	.40	.15	.07	.06	.09	.07		.14	65	1
W 12	Constr	---- do ------	20	4	96.20	.25	.20	.22	.07	.06	.08	.07	.07		.20	65	1
W 13	Constr	---- do ------	27	8	17.50	.47	1.09	.52		.73	.41	.24	.47		1.81	66	1
W 14	Constr	---- do ------	30	9	23.00	.40	.40	.40		.65	.31	.38	.47		1.30	66	1
W 15	Constr	---- do ------	30	9	25.40	.15	.32	.18		.27	.14	.24	.32		.72	66	1
W 16	Constr	---- do ------	41	12	11.50		2.47	1.25	1.30	.64	1.17	.40	.18	1.18	1.01	67	2
W 18	Constr	---- do ------	119	10	44.80	.46	.69	.51		.11	.13	.18	.16	.22	.17	68	1
W 19	Constr	---- do ------	127	10	36.80	.72	.84	.93	.19	.47	.31	.21	.25	.29	.21	68	1
W 20	Constr	---- do ------	22	3	39.20	.53	.53	.30		.20		.14	.09	.28	.34	69	1
W 21	Constr	---- do ------	24	3	16.60	1.09	.77	.80	.19	.24	.12	.15	.17	.62	.64	69	1
W 22	Constr	---- do ------	46	7	38.50	1.56	.76	1.43	.54	.32	.45	.15	.13	.56	.55	70	1
W 23	Constr	---- do ------	42	7	11.70	3.73	2.08	3.20	2.49	1.44	2.70		.77		1.53	71	1
W 24	Constr	---- do ------	51	6	28.00	.64	.81	1.76	.55	.48	.73	.26	.41	.52	.35	72	2
W 25	Constr	---- do ------	50	6	63.30	.96	.85	.49	.30	.21	.39	.26	.43	.65	.24	73	1
W 26	Constr	Excavation .	70	6	64.00	1.61	1.32	.67	.47	.27	.58	.47	.53	.92	.26	73	1
W 27	Constr	---- do ------	70	6	61.20	1.16	1.20	.75	.38	.42	.25	.32	.46	.63	.25	73	1
W 28	Constr	---- do ------	43	5	41.60	1.14	.85	1.26	.62	.73	.52	.71	.17	1.09		74	1
W 29	Constr	---- do ------	58	7	30.20		1.44	1.80	.84	1.04	.70	.85	.29	.89	1.46	74	1
W 30	Constr	---- do ------	27	6	42.60	.27	.28	.21	.04	.17	.07	.09	.07	.30	.40	75	1
W 31	Constr	---- do ------	85	6	65.30	.53	1.22	.75	.23	.32	.39	.12	.29	.15	.89	76	1
W 32	Constr	---- do ------	85	6	32.00	1.82	1.19	1.55	.46	.50	.73	.15	.47	.19	1.09	76	1

$* 2\sigma \rightarrow PPV = 438(SD)^{-1.52}$

Table 2.—Equations and statistics for ground vibration propagation

Site and component	Equation	Correlation coefficient	Standard error, pct
Site A:			
Maximum horizontal	$GV = 84.5\ (D/W^{1/2})^{-1.324}$	NA	NA
Vertical	$GV = 134.1\ (D/W^{1/2})^{-1.569}$	NA	NA
Radial:			
Site 1	$GV = 82\ (D/W^{1/2})^{-1.324}$	0.977	35
Site 2	$GV = 68\ (D/W^{1/2})^{-1.324}$	.971	35
Site 6	$GV = 54\ (D/W^{1/2})^{-1.493}$	.973	35
Site 7	$GV = 44\ (D/W^{1/2})^{-1.447}$	.902	85
Site 8	$GV = 135\ (D/W^{1/2})^{-1.475}$	.981	42
Site 9	$GV = 281\ (D/W^{1/2})^{-1.729}$	.980	47
Site 19	$GV = 79.2\ (D/W^{1/2})^{-1.383}$	.937	41
Vertical:			
Site 1	$GV = 137\ (D/W^{1/2})^{-1.551}$	.973	52
Site 2	$GV = 80\ (D/W^{1/2})^{-1.551}$	.968	52
Site 6	$GV = 56\ (D/W^{1/2})^{-1.333}$	.960	52
Site 7	$GV = 79\ (D/W^{1/2})^{-1.676}$	.972	34
Site 8	$GV = 110\ (D/W^{1/2})^{-1.312}$	.963	29
Site 9	$GV = 298\ (D/W^{1/2})^{-1.823}$	.984	42
Site 19	$GV = 335\ (D/W^{1/2})^{-1.825}$	.942	54
Transverse:			
Site 1	$GV = 64\ (D/W^{1/2})^{-1.234}$	.951	66
Site 2	$GV = 51\ (D/W^{1/2})^{-1.234}$	.931	66
Site 6	$GV = 55\ (D/W^{1/2})^{-1.362}$	.975	44
Site 7	$GV = 40\ (D/W^{1/2})^{-1.425}$	.944	54
Site 8	$GV = 50\ (D/W^{1/2})^{-1.257}$	.937	45
Site 9	$GV = 106\ (D/W^{1/2})^{-1.480}$	.940	59
Site 19	$GV = 64.2\ (D/W^{1/2})^{-1.381}$	.946	37
All Bureau of Mines coal mine data:			
Maximum horizontal	$GV = 133\ (D/W^{1/2})^{-1.50}$	.933	83
Vertical	$GV = 79\ (D/W^{1/2})^{-1.46}$	.923	88
* Total	$GV = 119\ (D/W^{1/2})^{-1.52}$	.936	92
Mines[1]:			
Radial	$GV = 52\ (D/W^{1/2})^{-2.37}$	NA	58
Vertical	$GV = 51\ (D/W^{1/2})^{-2.49}$	NA	59
Transverse	$GV = 73\ (D/W^{1/2})^{-3.13}$	NA	55
Quarries[1]:			
Radial	$GV = 14\ (D/W^{1/2})^{-1.22}$	NA	57
Vertical	$GV = 13\ (D/W^{1/2})^{-1.31}$	NA	61
Transverse	$GV = 10\ (D/W^{1/2})^{-1.11}$	NA	57
Construction[1]:			
Radial	$GV = 5.0\ (D/W^{1/2})^{-1.09}$	NA	85
Vertical	$GV = 8.9\ (D/W^{1/2})^{-0.99}$	NA	72
Transverse	$GB = 5.9\ (D/W^{1/2})^{-1.12}$	NA	80

NA = Not available
GV = Ground vibration, in/sec.
[1] From Lucole and Dowding (29).
D = Distance, ft.
W = Charge weight per delay, lb.

All Bureau coal mine vibration data are shown in figure 10. A vibration level of 1.0 in/sec was typically observed at a square root scaled distance of 23 ft/lb$^{1/2}$ and never observed beyond 60 ft/lb$^{1/2}$. The equivalent scaled distances for 0.5 in/sec peak particle velocity are 38 and 80 ft/lb$^{1/2}$. Wiss found that square root and cube root scaled distances required to enclose or envelope all his vibration data at 1.0 in/sec were 75 ft/lb$^{1/2}$ and 300 ft/lb$^{1/3}$, respectively (*56*). Two standard deviations of the summary data in figure 10 should leave roughly 2.5 pct of the points outside the upper limit. This corresponds to scaled distances of 55 and 90 ft/lb$^{1/2}$ at 1.0 and 0.5 in/sec, respectively. As alternatives to vibration monitoring or for statistical predictive purposes, the maximums represented by the envelopes (e.g., fig. 10) or two standard deviations from the mean regressions can be used; however, these will result in conservative vibration levels.

The Bureau of Mines coal data, as well as all of Lucole's (*29*), consist of relatively few measurements at each of a large variety of sites. Consequently, the pooled data representing each industry as a whole tends toward large scatter (high standard deviations).

Both Wiss (*56*) and Nicholls (*37*) utilized arrays of gages and found that the propagation from individual sites could reliably be quantified (fig. 7–9) and that vibration levels for individual sites could be reasonably predicted from scaled distances.

VIBRATION COMPARISONS: MINE AND QUARRY BLASTS

Vibrations from quarry blasting have been discussed extensively in Bulletin 656 (*37*). That report recommended two scaled distances intended to prevent the exceeding of 2 in/sec. For a site where propagation conditions were shown to be normal, a square root scaled distance of 20 ft/lb$^{1/2}$ was recommended. In the absence of any vibration monitoring, a scaled distance of 50 ft/lb$^{1/2}$ was to be used, based on the envelope of maximum observed values.

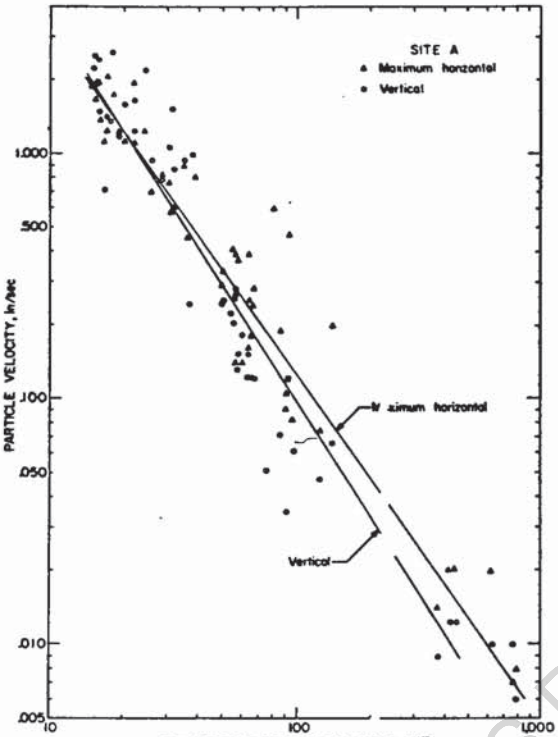

Figure 6.—Ground vibrations from a single coal mine. Equations are given in table 2.

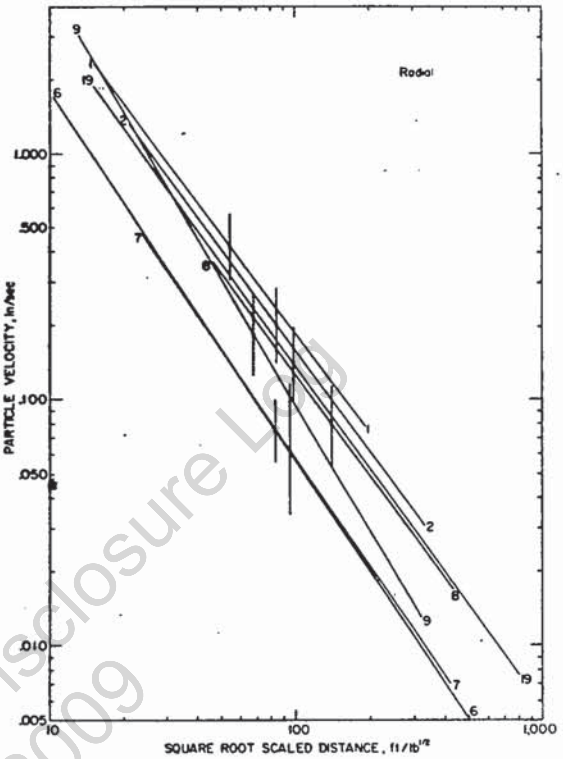

Figure 7.—Radial ground vibration propagations from surface coal mines.

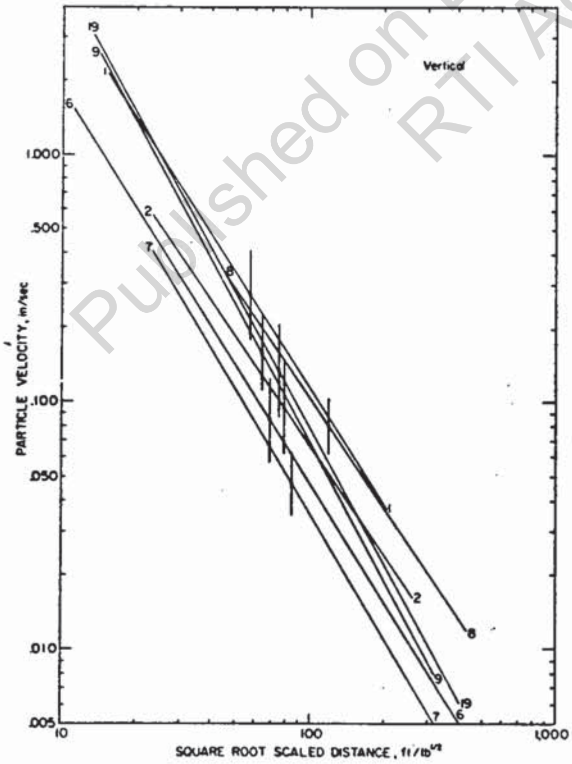

Figure 8.—Vertical ground vibration propagations from surface coal mines.

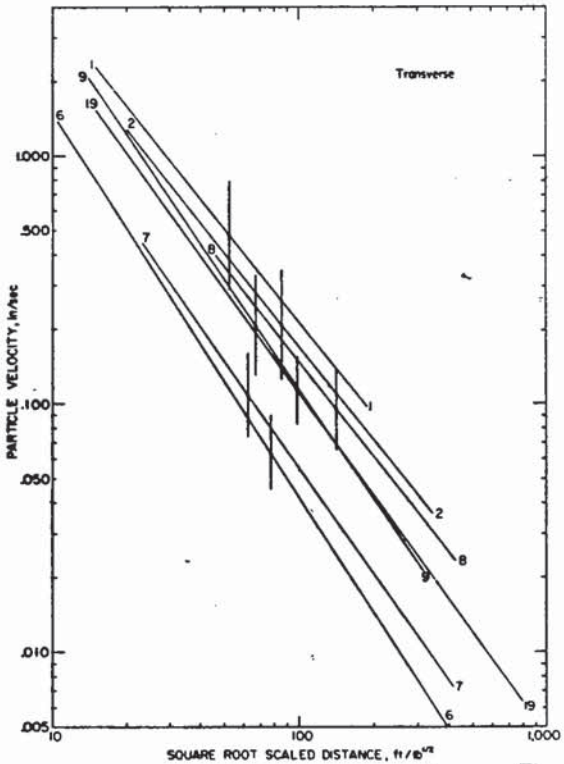

Figure 9.—Transverse ground vibration propagations from surface coal mines.

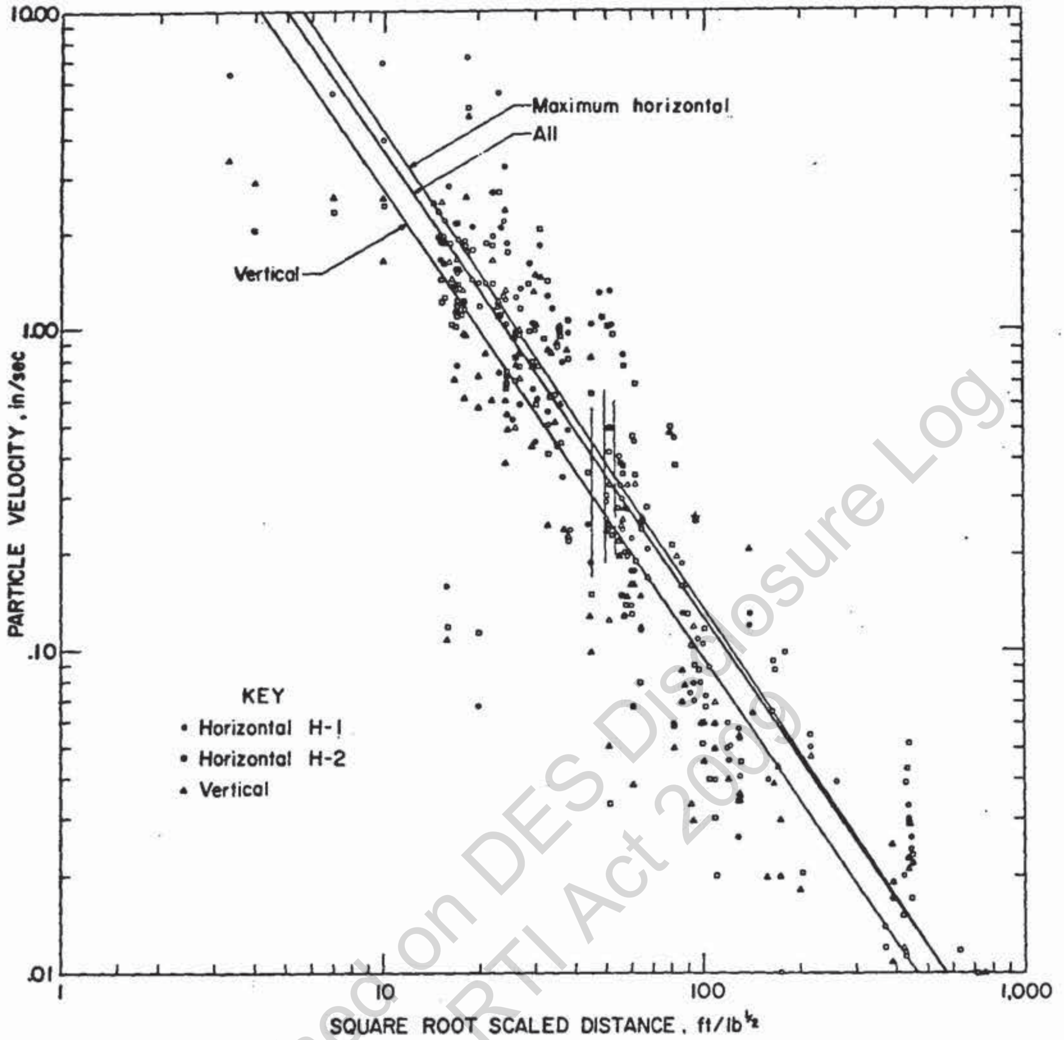

Figure 10.—Summary of ground vibrations from all surface coal mines. The component H–1 approximates "radial" and H–2 "transverse".

The overall zones encompassing the propagation regression lines for the radial motion (usually the largest) for coal mine and quarries are shown in figure 11. It is obvious that the vibration levels for coal and quarry blasting are similar, particularly at the smaller scaled distances that warrant most concern. Contrary to expectations, the coal mine vibrations were of greater amplitude than quarry vibrations at larger scaled distances. This is probably the result of larger absolute distances involved (for the relatively large charge weights) and the possible existence of slower decaying surface waves and dispersion-produced interference between delays at these distances. The Lucole study found different relative amplitudes between coal and quarry blasting to be more in agreement with the theoretical predictions (fig. 12). However, their data were also characterized by larger scatter and only a rough approximation to a Gaussian distribution (*29*). Their maximum envelope at 1.0 in/sec exceeded 200 ft/lb$^{1/2}$ for all kinds of blasting. Two standard deviations (95 pct) of the propagation data at 2 in/sec was less than 41 ft/lb$^{1/2}$ for coal mines and 33 ft/lb$^{1/2}$ for quarries and construction. These are both significantly lower than the Bureau's coal mine summary value of 55 ft/lb$^{1/2}$ from figure 10.

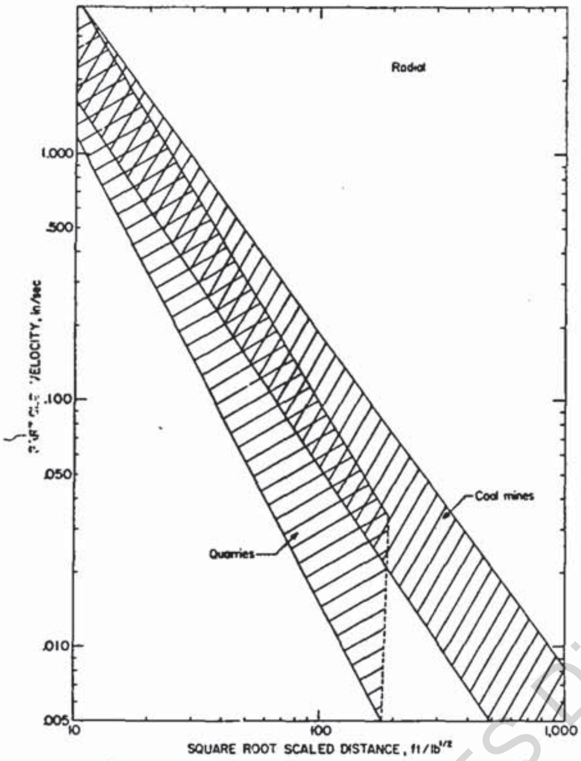

Figure 11.—Zones of mean propagation regressions for two major types of blasting.

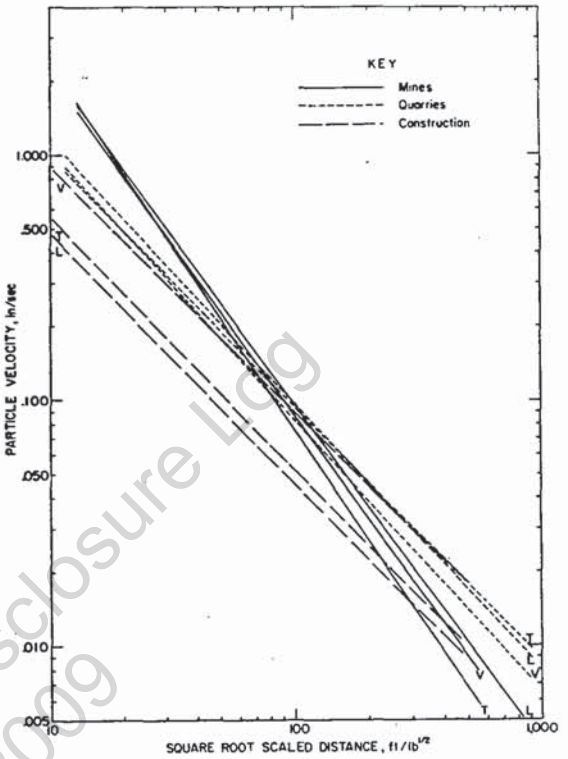

Figure 12.—Ground vibration propagation for three types of blasting as found by Lucole (*29*). Longitudinal (L), transverse (T), and vertical (V) components.

RESPONSE OF RESIDENTIAL STRUCTURES

The measured response of residential structures is a critical indicator of troublesome or potentially damaging ground vibrations. Corner motion measurements were used to assess the racking motions (shearing) of the gross structure (fig. 13). Essentially, cracking from blasts occurs where excessive stresses and strains are produced within the planes of the walls or between walls at the corners. Consequently, the vibration in the corners is assumed to indicate cracking potential, because it corresponds to whole-structure response. Other types of response cause different but consequential results. Midwall motions (normal to the wall surface) were also measured and are primarily responsible for window sashes rattling, picture frames tilting, dishes jiggling, and knick-knacks falling. Structures are designed to resist normal vertical load; however, differential vertical motions can produce high strains in floors and ceilings. Vertical floor motions are also of concern for potential human response.

RESPONSE SPECTRUM ANALYSIS TECHNIQUES

A simple method for predicting structural responses to vibrations has developed from studies of building response to earthquakes. It is based upon the single degree of freedom (SDF) model of a structure shown in figure 13 (*8, 10, 13, 24, 30, 32, 42*). The relative displacement between the mass and the ground, u(t), can be mathematically calculated from a knowledge of the time-varying ground displacements, y(t). The simplifying assumptions behind this mathematical idealization are as follows:

1. The structure can be represented by a lumped mass, m.
2. The relative displacement and deformation of the structure produces a restoring force proportional to the stiffness of the structure, k.
3. During vibration, energy is dissipated through viscous friction, C, which is constant regardless of the amplitude of the motion.

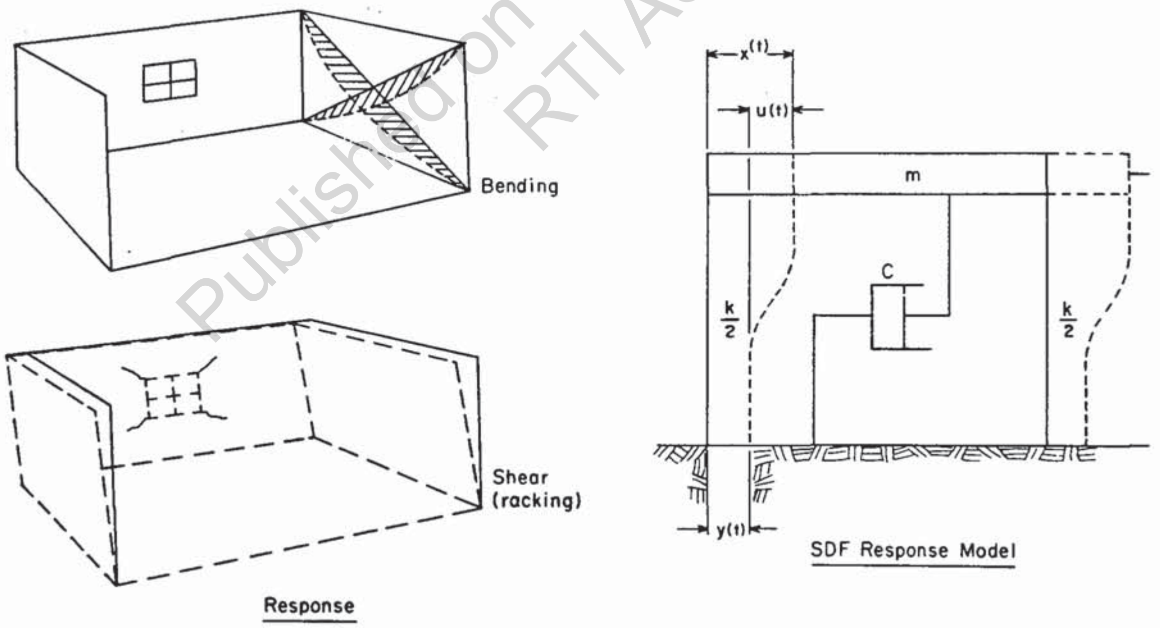

Figure 13.—Single degree of freedom (SDF) model and types of structures response. SDF symbols are explained in the text.

4. The structure responds or translates only in a single direction—hence the name single degree of freedom (SDF). Incorporation of simultaneous torsional rotation or additional components of motion requires additional degrees of freedom.

In an actual structure, m is the mass of the walls, floor, and roof; the restoring force is that produced by the walls resisting shear deformation, and frictional dissipation of energy results from portions of the structure working against each other. **Nail pulling is one consequence.** * The equation of motion of the SDF system, subjected to a time varying motion, is

$$\ddot{u} + 2\beta\omega_n\dot{u} + \omega_n^2 u = -\ddot{y} \qquad (1)$$

where $\ddot{u}$, $\dot{u}$, u, are relative acceleration, velocity, and displacement,
$\ddot{x}$, $\dot{x}$, x are absolute acceleration, velocity, and displacement of mass,
$\ddot{y}$, $\dot{y}$, y are absolute acceleration,velocity, and displacement of the ground,
ω_n is the circular natural frequency (also $2\pi f_n$) and related to stiffness (k) and mass (m) by: $\omega_n = \sqrt{k/m}$, and
β is the damping ratio (pct of critical/100) and equal to $C/\sqrt{km}$,
where C is the viscous damping and is equal to $\sqrt{km}$ when critical.

The natural frequency, ω_n, describes the rate at which the mass will freely oscillate when displaced. The damping, β, controls the decay of the oscillation. When a structure is critically damped (β = 1.0), it will return to its equilibrium position without oscillating.

Equation 1 can be solved for the relative displacement at any time, t, when given a transient ground particle velocity time history, $\dot{y}$. The solution is shown in equation 2:

$$u\,(t) = \int_0^t \dot{y}(\tau)e^{-\beta\omega_n(t-\tau)} \left\{\cos\left[\omega_n\sqrt{1-\beta^2}\,(t-\tau)\right] \overset{(-)}{\cancel{+}} \frac{\beta}{\sqrt{1-\beta^2}}\sin\left[\omega_n\sqrt{1-\beta^2}\,(t-\tau)\right]\right\} d\tau \qquad (2)$$

When a ground particle-velocity time history, such as shown in figure 3, is processed by computer with this equation, the modeled time history is produced.

The time history produced by equation 2 is one of relative displacements, u, rather than the absolute velocity $\dot{x}$, which is normally measured on the structure. In this relative displacement time history there will be a maximum, u_{max}. If that maximum relative displacement is multiplied by ω_n (or $2\pi f$), the resulting product, $2\pi f u_{max}$, is called the pseudo velocity, the PSRV, or the pseudo spectral response velocity. This pseudo velocity is a close approximation of the relative velocity, $\dot{u}$, when the assumption of simple harmonic motion is valid.

A response spectrum of a single ground motion, such as that of a hard-rock construction blast shown in figure 14, is generated from u_{max}'s from a number of different SDF systems. Consider two different components of the same structure, the 10 Hz gross structure and the 20 Hz wall. If the ground motions, $\dot{y}(t)$, of the construction blast are processed twice by equation 2 with β held constant at 5 pct and ω_n set to $2\pi(10)$ for the first time and $2\pi(20)$ for the second, two u_{max}'s will result: 0.01 in (0.25 mm) and 0.02 in (0.05 mm).

These u_{max}'s can be converted to two maximum pseudo velocities, $2\pi(10)\,(0.01) = 0.62$ in/sec (15.7 mm/sec) and $2\pi(20)\,(0.02) = 2.5$ in/sec (63.5 mm/sec); they are plotted in figure 14 as points *1* and *3*. If the ground motions from the construction blast are processed a number of times for a variety of ω's with β constant, the resultant pseudo velocities will form the solid line in figure 14.

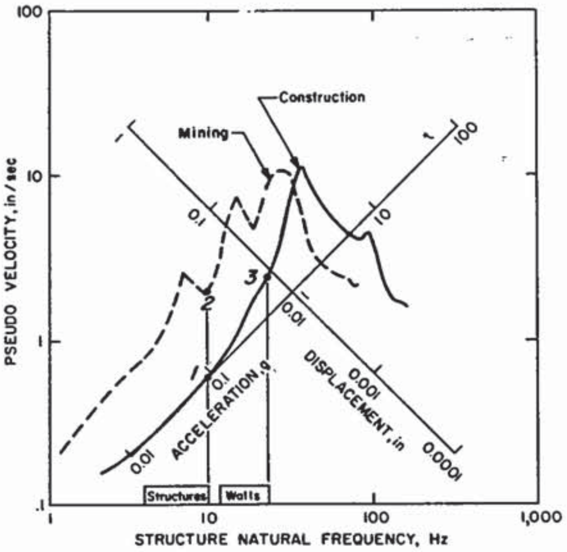

Figure 14.—Response spectra for mining and construction shots, after Corser (*8*).

The response spectra in figure 14 are plotted on four-axis tripartite paper. These four axes take advantage of the sinusoidal approximation involved in calculating a pseudo velocity. They are constructed so that the axis of the maximum relative displacement, u_{max}, is inclined upward to the left such that

$$u_{max} = PV/2\pi f,$$

where PV is the pseudo velocity, and that the axis of pseudo acceleration, PA, is inclined upward to the right such that

$$PA = PV \cdot 2\pi f.$$

The portion of a spectrum that is quasi-parallel to lines of constant displacement (less than 20 Hz for the mining blast in figure 14) is called the displacement bound. Likewise, the spectrum for the mining blast for frequencies greater than 50 Hz is the acceleration bound.

The response spectrum is similar to a Fourier frequency spectrum, since it shows the spectral content of a vibration time history. However, it is more useful as the pseudo velocity is calculated from a simplified measure of the maximum relative displacement, and as such it is related to wall strains that induce cracking.

Values of structure damping (β) must be assumed for computations of response spectra, and this value is 5 pct of critical in figure 14. This is a good approximation for a residence; however, the model response of residences is much more dependent on small changes in natural frequency than on small changes in damping (*32*).

Several researchers have applied response spectra techniques to blasting. Dowding examined responses from construction blasting (*10*). He shows the important relationship between the two frequencies (structure and ground motion) and how the ground motion descriptors of displacement, velocity, and acceleration affect response spectra of blasting vibrations. Most significant for blasting is that the principal frequencies of the ground motion almost always equal or exceed the gross structure natural frequencies of 4 to 10 Hz. This suggests either a displacement- or velocity-bound system in the 5- to 10-Hz range and supports the use of these motion descriptors to assess cracking potential. Earthquakes and nuclear blasts generate low principal frequency motions at the large distances of concern, and the 4- to 10-Hz range falls on the acceleration bound of the spectra.

Medearis developed response spectra for a variety of production blasts (*30*). This was one of the first attempts to show statistically that the structural response of residences (and consequently the cracking potential) is related to frequency content of the blasts. Medearis recommended safe particle velocities based on distances from the blasts that implicitly include the above-described frequency dependencies. These range from 3.20 in/sec (10 ft from a 2-story residence) to 0.62 in/sec (10,000 ft from a 1-story residence) and are based upon a 5-pct tolerance of damage. Medearis' suite of time histories was taken from quarry, excavation, and construction blasts, with an average spectral peak of 40 Hz. He therefore predicted that the relatively higher frequency 1-story homes with natural frequencies nearer 10 Hz are more damage-prone than taller 2-story homes with natural frequencies near 5 Hz. These results would not apply to mine blasts having ground vibrations at lower frequencies.

Corser calculated response spectra for a variety of blasts recorded by the Bureau of Mines (*8*). He found that, in the 5- to 10-Hz range (fundamental frequencies for wood frame structures), mining blasts generated SDF relative displacements that averaged 5.7 times (2.9 to 9.3) those of close-in construction shots. The time histories analyzed had peak particle velocities of 0.66 to 2.23 in/sec. Since the relative structure velocities will have similar ratios, the safe vibration levels for these two classes of blasts could differ by that same factor (5 to 6).

Figure 14 compares spectra from ground motions generated from surface coal mining and construction blasting in hard rock. Even though these two blasts produced peak particle velocities of 2.3 in/sec, the gross structure of a 1-story residence (represented by the 10 Hz response) would respond to the surface mining vibrations with relative displacements 3 times that of the higher frequency motions produced by the construction blasts.

Response-spectra analysis techniques are a powerful tool for research, engineering, and design because they include the important frequency effects. They can predict responses of a variety of structures for any type of time history. However, they do have some serious limitations in that their validity depends on how closely the structures fit the SDF model. They are not required for situations where responses can be determined empirically. They are not practical for regulatory purposes, as they are too complex and time consuming for agencies responsible for measurement and monitoring compliance. Where responses and damage potentials have been established for one type of structure, response spectra analysis allows predictions for quite different structures with unknown vibration character. Since taller structures better fit the SDF model, these techniques have been used widely for predictions of earthquake and nuclear blast effects on such structures.

DIRECT MEASUREMENT OF STRUCTURE RESPONSES

Measurements were made of structure motions, produced by both the ground-borne vibration and airblast, as part of the assessment of potentially damaging blasts. The measurement and recording systems have been described in Bureau reports (*45, 50*). Both ground and structure measurements were made with 2.50- and 4.75-Hz velocity transducers (Vibra-Metrics[6] 120 and 124) with flat frequency responses (-3 dB) of 3 to 500 Hz and 5 to 2,000 Hz, respectively. A few accelerometers, having low-frequency response down to 1 Hz, and a variety of blasting seismographs were used (*50*).

Test Structures

A total of 76 different structures were studied for ground vibration and airblast response and damage (table 3). All were houses except Nos. 13, 15, 16, and 50, which were 1- and 2-story structures somewhat larger than single-family residences, and No. 54, which was a mobile home. Some structures (Nos. 19 and 20) were studied in conjunction with highwall, parting, and surface blasts. The response of structures 1–6 was described in an earlier study (*45*). Of the 76 structures, only 14 were subjected to high enough levels for significant damage and nondamage data, although levels of response were measured for every structure. The 14 significant test houses are shown in figures 15–28.

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[6] Reference to specific brand names is made for identification only and does not imply endorsement by the Bureau of Mines.

Figure 15.—Test structure 19, near a coal mine.

Table 3.—Test structures and measured dynamic properties

Structure	No. of stories	Dimensions, ft		Construction				Natural frequency of structure, Hz		Damping, pct		Midwall natural frequencies, Hz	Midwall damping, pct	Shots (table 1)
		Plan NS × EW	Overall height	Superstructure	Exterior covering	Interior covering	Foundation	N-S	E-W	N-S	E-W			
1	1	22×30	14	Wood frame	Wood siding	Gypsum wallboard	Full basement					16		13,14,17,18
2	1	30×70	14	Masonry and wood	Stone	---- do	---- do							15
3	1½	35×35	16	Wood frame	Brick and wood	---- do	Partial basement					13		16
4	2	30×40	22	---- do	Wood siding	---- do	Full basement	8		2		19,22		17,18
5	2	40×40	22	---- do	Brick and wood siding.	---- do	Partial basement					19		19
6	1	40×40	14	---- do	Wood siding	---- do	Full basement	9				32		19
7	1	48×25	15	---- do	Asbestos siding	---- do	---- do							33
8	1	15×10	12	---- do	Wood siding	---- do	Concrete slab							33
9	1	61×29	14	---- do	---- do	---- do	Full basement							34
10	2	44×29	22	---- do	Asphalt sheathing	Plaster	---- do							35
11	2	26×32	30	---- do	Masonite siding	Gypsum wallboard	---- do					36		35
12	1½	27×36	20	---- do	Cedar shakes	---- do	---- do					25		35
13	1	34×100	16	---- do	Brick and stucco	---- do	Slab and crawlspace							35
14	1½	35×35	23	---- do	Wood siding	---- do	Full basement	10		7		14		36,38
15	1	125×25	12	Steel frame	Steel	---- do	Concrete slab	6		3		17		36,38
16	1	80×80	17		Brick and stucco	---- do	Full basement					8.3		36
17	1½	19×40	20	Wood frame	Wood shingles	---- do	---- do	10	9	5	7	18		37,146
18	1	44×28	13	---- do	Wood siding	---- do	Pillars in dirt	6	10	7	7	11.4		37,146
19	2	33×35	24	---- do	Wood siding	Plaster and lath	Partial basement	4	4	13	13	13,17	4.5,5.1	39–48,59–96
20	1½	39×29	21	---- do	---- do	Gypsum wallboard	Full basement	8	7	3	8	20	3.1	42–58
21	1	48×28	15	---- do	---- do	---- do	---- do	7	7	2	7	13.4,14.5	2.9,2.3	97–102,110, 111,113, 114,117, 135,136
22	2	27×76	26	---- do	Brick and masonite	Gypsum and paneling.	Crawl space	8	6	3	4	12.3,13.1	2.0,3.0	103,104
23	1	62×26	14	---- do	Asbestos shingles	Gypsum wallboard	---- do	9	7	2	5	18.5		103–105
24	1	24×55	15	---- do	Brick	---- do	Crawl space	10	10	2	4			106
25	1½	41×24	22	---- do	Wood siding	---- do	Full basement	8	10	8	3	13.7,16.3	1.8,3.6	106
26	1	40×31	15	---- do	Aluminum siding	---- do	Crawl space	7	8	6	4			107
27	1	51×30	15	---- do	Wood siding	Plaster and lath	Partial basement	7	6	10	6	17,24		1–11
28	1	42×28	14	---- do	Wood and aluminum.	Gypsum wallboard	Crawl space	7	8	6	4			108,122
29	2	26×35	22	---- do	Wood panel	---- do	---- do	7	8	2	2	17.7,13.0	1.1,2.2	109,120,121
30	1	34×48	16	---- do	Stone	---- do	Full basement							112
31	1	35×44	13	---- do	Wood siding	---- do	Crawl space	8	6	2	2	12.2,16.6	1.5,1.2	115,116,118
32	1½	58×26	22	---- do	Brick and masonite	Paneling and wallboard.	Concrete slab							119
33	1½	69×27	24	---- do	Stone	Gypsum wallboard	Full basement	8	9	2	2	16.0,19.7	1.5,2.1	124,125,132–134,137–139
34	1	33×33	18	---- do	Asphalt sheathing	Plaster	Crawl space	7	6	3	4			126,127, 130,131
35	1	32×37	18	---- do	---- do	Gypsum wallboard	---- do	7	6	1	4			128,129,140
36	1	28×40	14	---- do	Asphalt shingles	---- do	---- do	6	7	3		14,17		141–145
37	1½	32×26	20	---- do	Wood siding	Plaster and lath	Full basement	9	10	2	2	18.5,20		146,150
38	2	28×32	20	Masonry and wood.	Brick and aluminum.	Wood paneling	Concrete slab	4	6	5	3			147,148

Table 3.—Test structures and measured dynamic properties—Continued

Structure	No. of stories	Dimensions, ft		Construction				Natural frequency of structure, Hz		Damping, pct		Midwall natural frequencies, Hz	Midwall damping, pct	Shots (table 1)
		Plan NS × EW	Overall height	Superstructure	Exterior covering	Interior covering	Foundation	N-S	E-W	N-S	E-W			
39	1	34×29	15	Wood frame	Masonite siding	Paneling and wallboard	Full basement	5	5	7		14		147
40	1½	28×31	18	do	Stucco	Plaster and lath	Partial basement	5	8	7	2	13.6		148
41	2	40×28	22	do	Wood siding	Gypsum and plaster	Full basement	10	8	4	2	16.6		149
42	1½	44×30	20	do	do	Paneling	do	5	7	5	4	11.9,13.9		151–153
43	1½	28×46	23	do	do	do	do	8	5			18,18		154
44	1		15	do	do		do			11,11				155–156
45	2	55×44	32	Solid brick	Brick	Plaster on brick	do	9	10	3	3			157–159
46	1½	38×40	21	Concrete block	Concrete block	Plaster	do	10		4		11,11		157–159
47	1	87×38	15	Wood frame	Brick	Gypsum wallboard	do					12.5,13.3		160
48	1½	36×24	22	do	Wood siding	do	do					16.7,16.7		161
49	1½	41×35	27	do	do	Gypsum wallboard and plaster on lath						18.2,18.2		162,164–166, 172,197,200.
50	1	48×180	14	do	Aluminum siding	Gypsum wallboard	Concrete slab	9		2				163
51	2	50×43	28	Solid brick	Brick	Plaster on brick and lath	Full basement							167–171, 173–182
52	1	37×24	16	Wood frame		Wood paneling	do							183
53	1	24×35	15	do	Wood siding		Crawl space							184
54	1	12×60	15	Metal walls	Metal	Paneling	None							186,187, 189–192
55	1½	40×31	23	Wood frame	Wood siding		Full basement							193
56	1½	34×57	20	do	Wood siding		do							194,196
57	1	40×24	20	Wood frame	Aluminum siding	Plaster and lath and paneling	Sandstone blocks partial basement		8		9.6			198,199, 201,202 203–209
58	1	40.4×31	26	Brick and masonry	Brick and masonry	Brick and gypsum wallboard	Masonry basement							W–1
59	1	30.5×54		Wood frame	Wood siding	Gypsum wallboard	Continuous concrete footings							W–2
60	2	54×26.5		do	Aluminum siding	do	do							W–4,W–5
61	1	28.5×55.5		do	Brick and plywood	Gypsum wallboard and plaster	Concrete block							W–6
62	2	34.5×48		do	Board and bat	Gypsum wallboard	Slab on grade	11	5	3	8			W–7,W–8
63	2	76.8×80		do	Wood siding	Plaster	Wooden piers on spread footings							W–9,W–10
64	2	34.5×48		do	Board and bat	Gypsum wallboard	Slab on grade							W–11,W–12
65	1	26×25		do	Aluminum siding	do	Continuous concrete footings	8		6				W–13,W–14,
66	1	26.5×34.5		do	Wooden shingles	do	do							W–15 W–16,W–17
67	2	19.5×46.5		do	Wood siding	Wood paneling except kitchen ceilings	Concrete block	8		6				W–18,W–19
68	1	55×34		do	Board and bat	Gypsum wallboard	do							W–20,W–21
69	1	41×37.5		do	Aluminum siding	do	do							W–22
70	1	33×44.5		do	Wood panels	do	Continuous concrete footings							W–23
71	1	23.5×23.5		do	Board and bat	Unfinished	do							W–24
72	2	41.5×28.5		do	do	Wallboard paneling	do							W–25,W–26,
73	1	30.5×26.5		do	Asphalt shingles	Plaster	Concrete							W–27 W–28,W–29
74	1	28×45		do	do	Wallboard	Slab and concrete block	7	7	6	9			W–28,W–29
75	1	36.5×34		do	Plywood	Gypsum wallboard	Concrete							W–30
76	1	38.5×40.5		do	Wood plank	Wallboard	do							W–31,W–32

→ SEE ERRATA

Figure 16.—Test structure 20, near a coal mine.

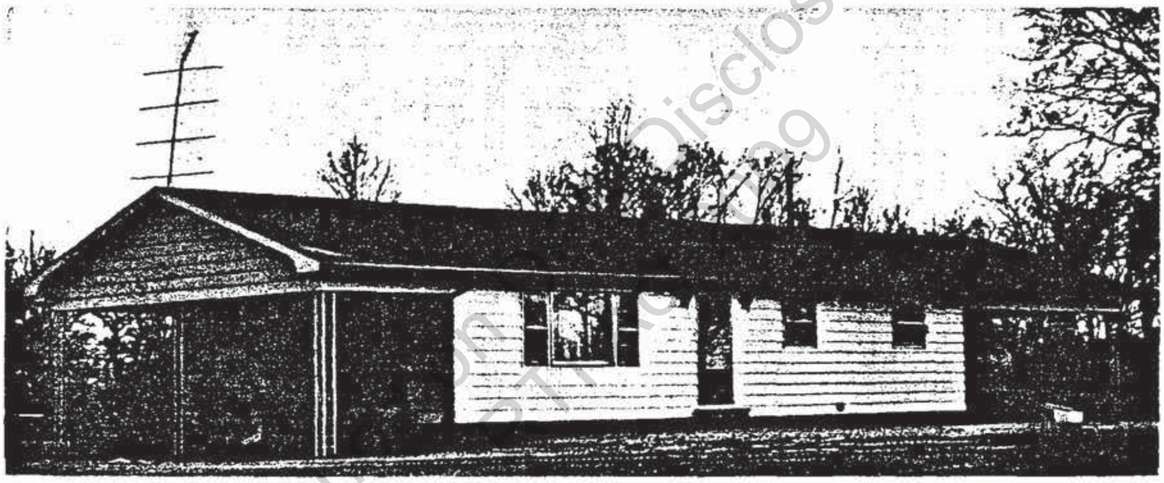

Figure 17.—Test structure 21, near a coal mine.

Figure 18.—Test structure 22, near a quarry.

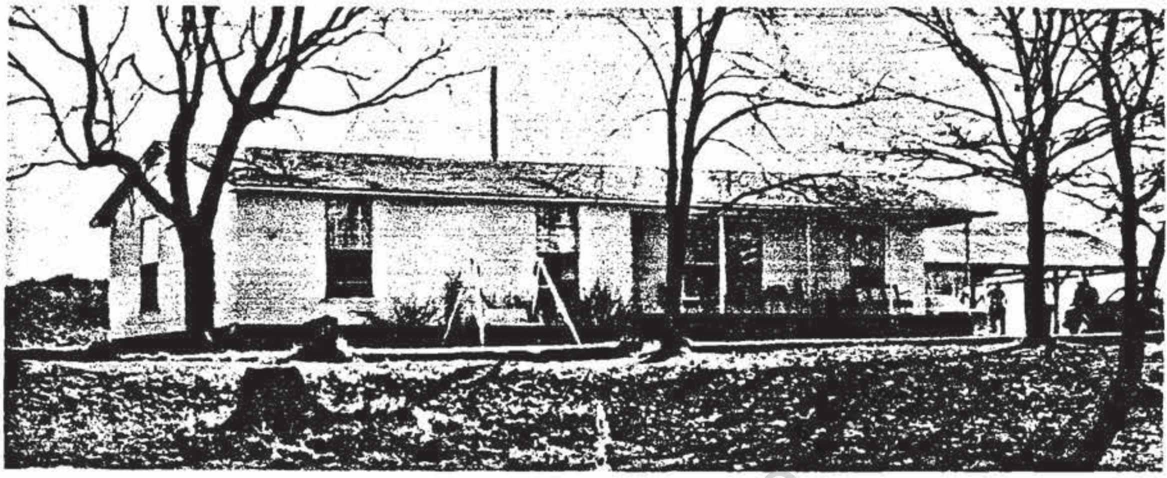

Figure 19.—Test structure 23, near a quarry.

Figure 20.—Test structure 26, near a coal mine.

Figure 21.—Test structure 27, near a coal mine.

Figure 22.—Test structure 28, near a coal mine.

Figure 23.—Test structure 29, near a coal mine.

Figure 24.—Test structure 30, near a coal mine.

Figure 25.—Test structure 31, near a coal mine.

Figure 26.—Test structure 49, near a coal mine.

Figure 27.—Test structure 51, near a coal mine.

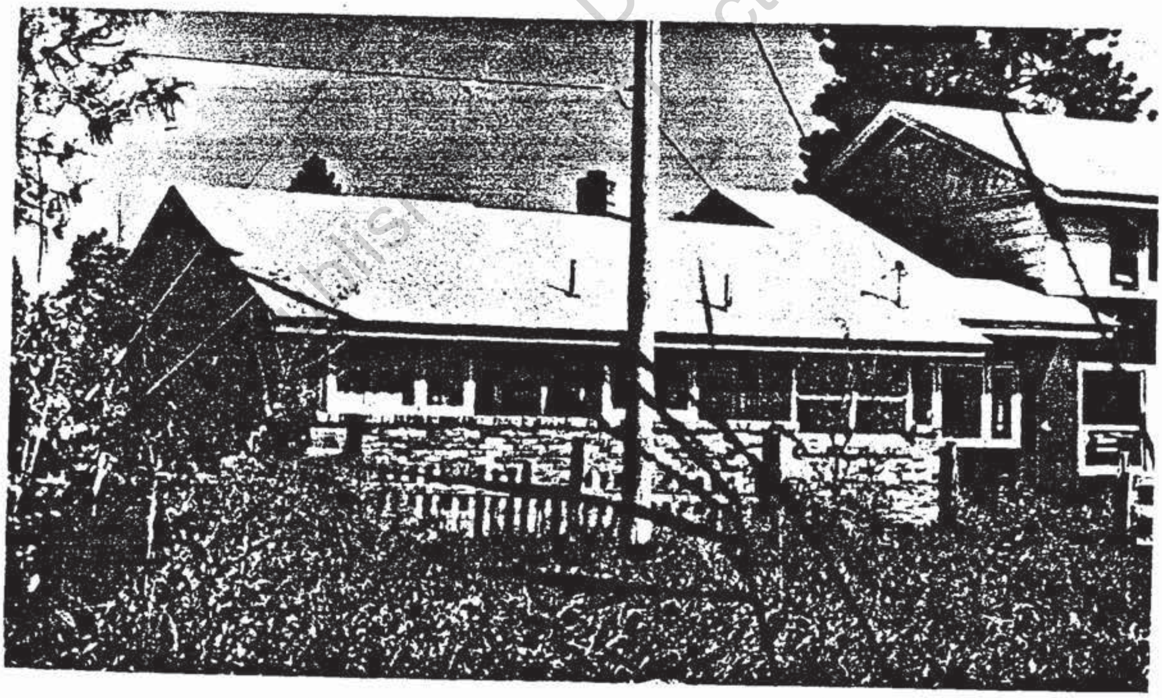

Figure 28.—Test structure 61, near a ~~coal mine~~.
Construction Site

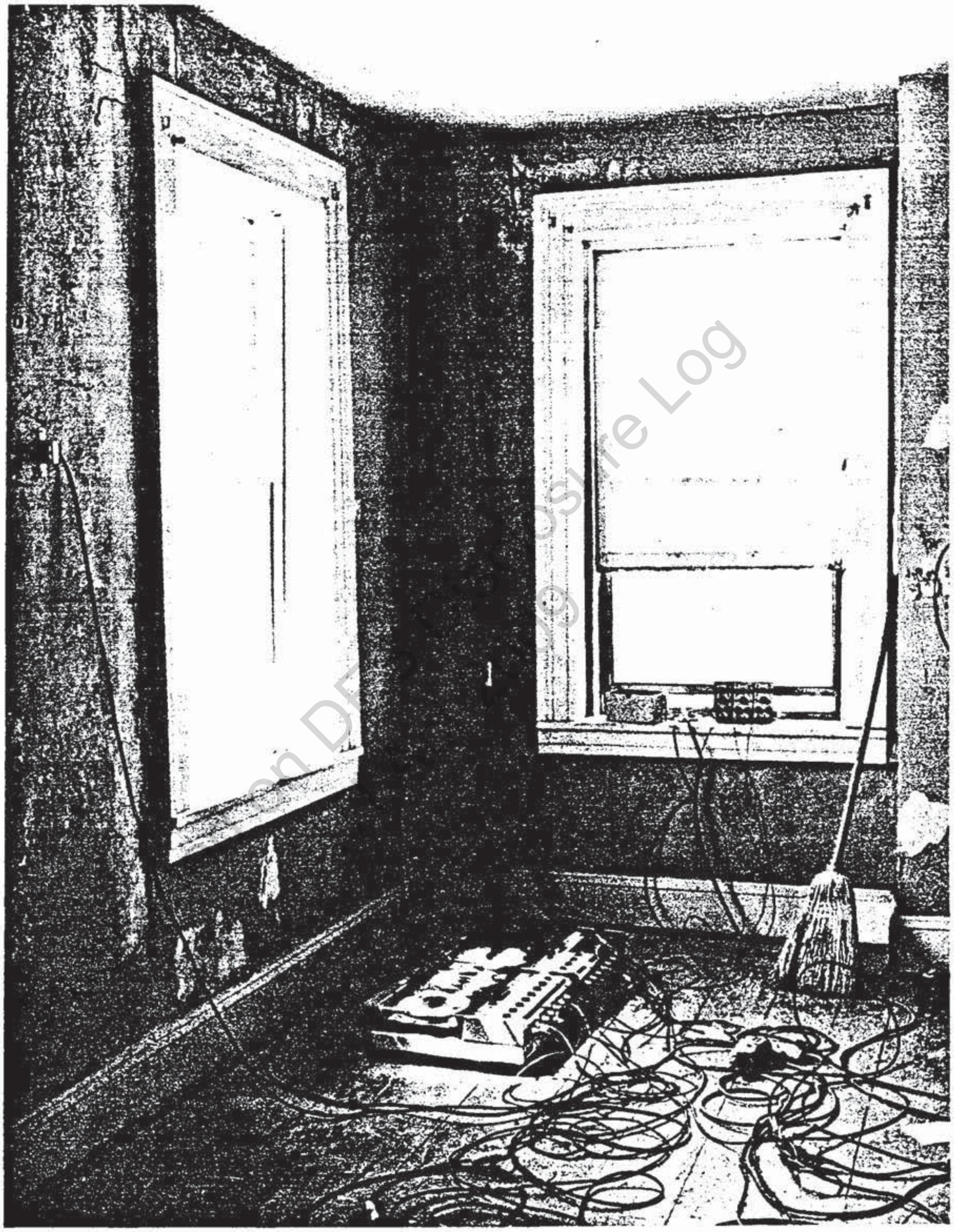

Figure 29.—Vibration gages mounted in corners and on walls for measuring structure response in structure 51.

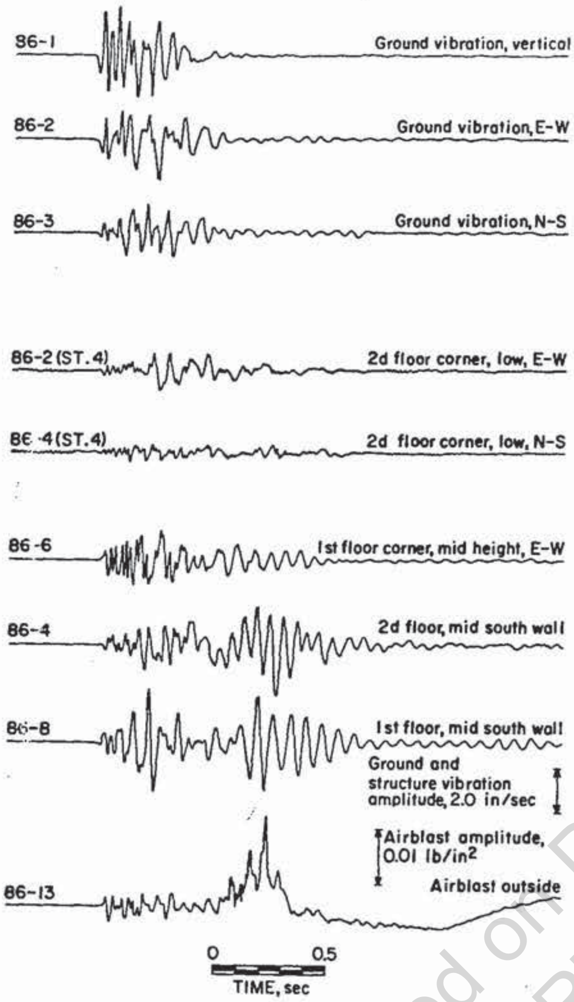

Figure 30.—Ground vibration, structure vibration, and airblast time histories from a coal mine highwall blast.

Instrumenting for Response

Outside ground vibration, airblast, structure corner, and midwall responses were measured for each shot. The ground vibration was measured by three orthogonal 2.5-Hz velocity gages buried about 12 inches in the soil next to the foundation (*50*). Outside airblasts were measured with at least one pressure gage and two sound level meters, one reading C-slow (*46*). The structures were instrumented for horizontal motions by a pair of gages mounted on the first-floor vertical walls in the corner closest to blasts and on one or more midwalls (fig. 29). Typically, the vertical motion was also measured in the same corner. Extra recording channels that were available were used for additional corner motions (at midheights, near the ceiling, or on the next floor); additional floor motions (e.g., midfloor verticals); basement wall horizontals; opposite corner responses (for torsional motions); and inside noise. A typical set of time histories is shown in figure 30. This particular shot produced strong airblast responses of the midwalls.

Natural Frequency and Damping

Natural frequency, ω_n, and damping, β, are the most important structure response characteristics. The structural natural frequencies as measured from blast-produced corner motions are summarized in figure 31, with individual values listed in table 3. Structures continue to vibrate after the sources (ground vibration and airblast) decay, and natural frequencies and damping can be measured from these free vibration time histories. The variations of structures, especially midwalls, are approximately sinusoidal; therefore, the natural frequencies are the inverse of the periods in seconds. Damping values calculated from free vibration motions are given by:

$$\beta = \frac{100}{2\pi m} \mathrm{Ln}(A_n/A_{n+m}),$$

where β is the percent of critical damping, A is the peak amplitude at the n^{th} cycle, and m is any number of cycles later. Dowding (*13*) and Langan (*24*) discuss the general problem of structure frequencies and damping. Their works include transfer function methods for calculating ω_n and β as well as amplitude-dependence of the damping value. Murray (*32*) computed many of the damping and frequency values in table 3, some of which were later reanalyzed by Langan (*24*).

Little difference in natural frequencies was observed among 1- and 1½-story homes; however, that for the 2-story homes was lower. Dowding (*13*) found average natural frequencies for the three types of homes of 8.0, 7.4, and 4.2 Hz, respectively. Medearis (*30*) measured frequencies and damping values for 61 houses and found similar results, except for some higher frequencies for the 1- and 1½-story homes. He found frequency ranges of 8 to 18 Hz (1-story), 7 to 14 Hz (1½-story) and 4 to 11 Hz (2-story). Damping, found by both investigators to vary between 2 and 10 pct, is summarized in figure 32.

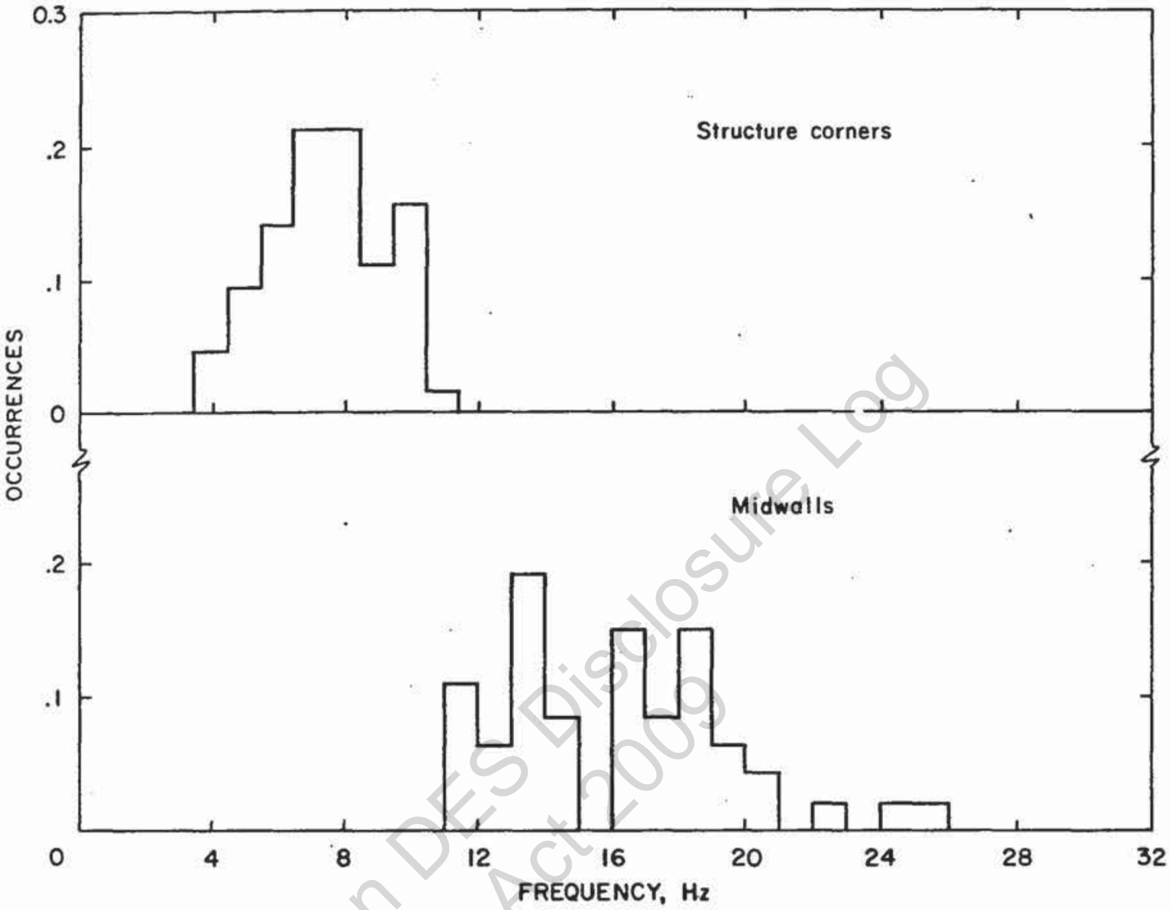

Figure 31.—Residential structure natural frequencies.

Production Blasting

Levels of structure response and incidents of damage were sought for 225 production blasts (table 2). A wide range of charge sizes, distances, geologies, and blast types produced vibrations of various peak values, durations, and frequency character. Quarries in urban areas had high free faces, used multiple decks, and had hole diameters seldom exceeding 5 in. Shots 21 to 30 were in an isolated quarry with high vibration levels at the close-in locations, but no house vibration measurements were made.

Coal mine highwall blasts varied from well-confined blasts producing no throw whatsoever, to quarry-type blasts with three free faces (top, front, and one side). Where ground vibration appeared to be more serious than airblast, design emphasis for production blasts was placed on sufficient relief (maximum number of free faces). Parting shots involved blasting a thin and often hard rock layer, and often produced high levels of airblast and low ground vibration. An extensive study of blast design and resulting vibration levels and character was made by Wiss (*56*) and will not be discussed further in this report.

Velocity Exposure Levels

In addition to analyzing particle velocity time histories for peak values and frequency character, ground vibrations were also processed for velocity exposure levels (VEL), which are analogous to sound exposure levels (SEL) for noise (*22, 49*). These methods measure the energy of a signal within specified frequency limits and time intervals. The use of VEL to assess structure response is a possible alternative technique to using the simple peak levels of the particle

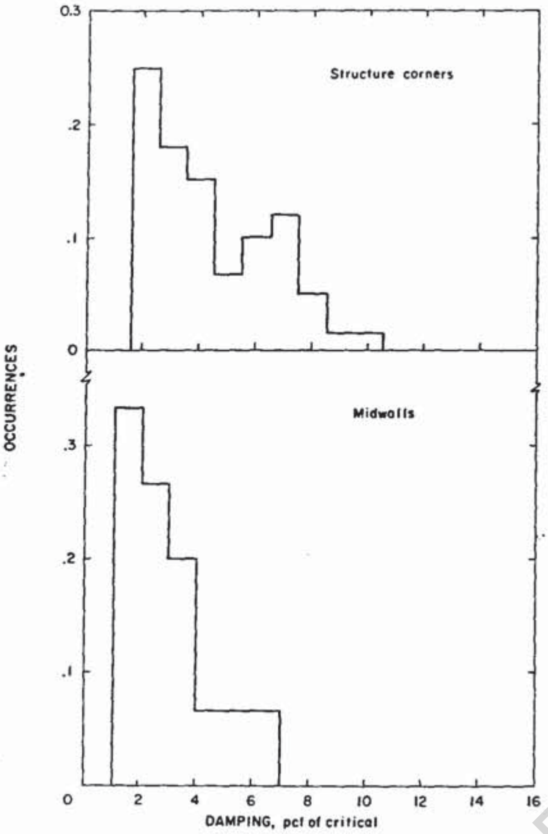

Figure 32.—Residential structure damping values.

velocity and also to response spectra techniques. The ideal VEL is normalized to 1 sec; therefore, this penalizes excessively long events (3 dB per doubling of duration) and allows higher levels for short-duration events. Current field practice involves the use of an rms system (e.g., sound level meter) with either ⅛- or 1-sec time constants and optional filtering.

Velocity exposure levels were determined for 200 of the measured blasts, with an rms detecting and filtering system described by Stachura (*49*) and defined by:

$$VEL = 10 \log_{10} \left[\frac{1}{t_o} \int_o^T v^2(t)\, dt \right]$$

where $t_o = 1$ sec, v(t) the time-varying filtered particle velocity, and T the various integration times. A filter range of 1 to 12 Hz was employed to include the range of whole-structure natural frequencies. Integration times were ⅛, ¼, 1, and 2 sec. The 1-sec time was an overall compromise that was long enough to include all the significant energy in a typical mine blast vibration measure near the source. VEL values were also determined for structure as well as ground motions.

Structure Responses From Blasting

Structure and midwall responses from production mine blasting are shown in figures 33–37, with the statistics given in table 4. In all cases, the corner and midwall responses from any given blast were plotted against the corresponding ground vibration components. The horizontal vibration components did not necessarily correspond to the true radial (or longitudinal) and transverse, since the velocity gages were oriented parallel to the structure walls.

Most interesting is that the racking response (absolute corner horizontal vibration) as shown in figures 33 and 34 is significantly lower than the input ground vibration velocity, when measured at either the first or second floor, or low or high in the corner. The vertical ground and structure corner vibrations were roughly equal as expected (figs. 33 and 36). The differences in the responses between types of blasts were significant. However, very little difference was observed between the 1- and 2-story structures.

All the responses discussed in this paper are applicable to residential-type structures with wood frame superstructures. The values do not apply to multistory steel frame structures or large structures with masonry load-supporting walls. The natural frequencies of vibration of these structures could be considerably lower than the 4 to 24 Hz range for residences and their midwalls.

The ground motion VEL did not correlate significantly better to the measured peak or VEL of the structure than the use of simple peak versus peak. Consequently it is recommended that peak velocities continue to be the primary measure of ground motion to assess the damage potential to residential-type structures and for regulatory purposes. However, it is recognized that for engineering, design, and research involving a variety of types of structures and sources, a measurement of simple peak particle velocity is an oversimplification. Some type of direct measurement of response (preferably dynamic strain) or model prediction (such as response spectra) would be appropriate in such cases.

Amplification Factors

Several analyses were made of structure response amplifications of the ground vibrations. The Bureau of Mines structure motion data were analyzed by Murray (*32*), Langan (*24*), and Dowding (*13*) for Fourier transfer functions and response characteristics. They discussed the problem of "ghost" resonances (dividing a small apparent response in the spectrum of the structure's motion by an even smaller spectral value in the ground motion).

A simpler amplification factor was determined directly from the vibration time histories. Maximum structure velocities and their times of occurrence were noted. Ground velocities and frequencies were then picked off the records at the corresponding moments of time or immediately preceding the time of the peak structure vibrations. The ratios of the two velocities are plotted in figures 38–40 against the frequency of the corresponding ground motion peak. Amplification factors for the racking response of a 1-story and a 2-story structure are shown in figure 38. Maximum amplifications were found to be associated with ground motions between 5 and 12 Hz, as expected from the natural resonance frequencies of the residences. Because

Table 4.—Equations and statistics for peak structure responses from ground vibrations

Descriptor[1] and mine type	Stories, home	Equation	Correlation coefficient	Standard error, in/sec	Normalized std. error, in/sec	Regression line (figs. 33–37)	Number of points
Max.H SV versus Max. H GV:							
Coal	1	SV = 0.049 + 0.557GV	0.936	0.084	0.090	NAp	36
Do	2	SV = .075 + .553GV	.870	.151	.174	NAp	34
Do	All	SV = .060 + .559GV	.898	.120	.120	1	70
Construction	All	SV = .136 + .230GV	.599	.140	.234	2	13
Iron range	All	SV = .052 + .976GV	.894	.117	.130	3	10
All	1	SV = 0.87 + 435GV	.741	.169	.228	NAp	50
All	2	SV = .082 + .561GV	.862	.141	.163	NAp	53
All	All	SV = .084 + .496GV	.800	.157	.197	4	103
Vert. SV versus Vert. GV:							
Coal	1	SV = .048 + .771GV	.928	.063	.068	5	26
Do	2	SV = .070 + 1.124GV	.880	.335	.335	6	62
Do	All	SV = .044 + 1.131GV	.892	.286	.320	NAp	88
Construction	1	SV = .112 + .230GV	.568	.127	.223	7	11
Do	2	SV = .090 + .529GV	.859	.233	.271	8	7
Do	All	SV = .054 + .424GV	.741	.193	.260	NAp	18
All	1	SV = .035 + .738GV	.905	.208	.230	NAp	37
All	2	SV = .115 + .942GV	.896	.364	.406	NAp	69
All	All	SV = .073 + .907GV	.893	.330	.370	NAp	106
Max.H midwall, SV versus Max.H GV:							
Coal	1	SV = .154 + 1.347GV	.927	.228	.246	9	47
Do	2	SV = .153 + 1.636GV	.920	.358	.389	10	53
Do	All	SV = .146 + 1.534GV	.918	.310	.337	NAp	100
Construction	1	SV = .191 + .300GV	.754	.121	.160	NAp	8
Do	2	SV = .170 + .928GV	.754	.202	.268	NAp	7
Do	All	SV = .269 + .275GV	.524	.194	.371	11	15
Quarry	All	SV = .025 + 1.106GV	.886	.202	.228	12	19
Iron range	All	SV = .029 + 2.546GV	.722	.147	.203	13	16
All	1	SV = .196 + .904GV	.868	.331	.382	NAp	77
All	2	SV = .218 + 1.181GV	.776	.498	.642	NAp	82
All	All	SV = .217 + 1.002GV	.803	.431	.537	NAp	159
Coal, single home:							
Max.H SV versus MaxH GV	2	SV = .114 + .472GV	.894	.114	.161	14	35
H_1 SV versus H_1 GV	2	SV = .114 + .472GV	.894	.144	.161	NAp	35
H_2 SV versus H_2GV	2	SV = .019 + .370GV	.906	.091	.101	NAp	37
Max.H SV versus Max VEL H GV	2	SV = .128 + 2.451GV	.812	.189	.232	15	37
H_1 SV versus VELH_1GV	2	SV = .128 + 2.451GV	.812	.189	.232	NAp	37
H_2 SV versus VELH_2 GV	2	SV = .057 + 1.563GV	.854	.113	.132	NAp	38
Max.H SV versus TVS GV	2	SV = .110 + .299GV	.789	.143	.181	16	28
Max.HSV versus VELTVS GV	2	SV = .158 + 1.171GV	.763	.211	.276	NAp	29
Vert.SV versus Vert.GV	2	SV = .140 + 1.119GV	.852	.403	.472	17	33
Max.H midwall SV versus MaxH. GV	2	SV = .152 + 1.567GV	.905	.428	.472	18	28
Midwall H_1 SV versus H_1 GV	2	SV = .151 + 1.567GV	.905	.428	.472	NAp	28
Midwall H_2 SV versus H_2 GV	2	SV = .514 + 1.517GV	.830	.431	.519	NAp	37
Max.H SV versus PVS GV	2	SV = .092 + .267GV	.781	.128	.164	19	26

NAP = Not applicable.

[1] Symbols SV = Structure vibrations, in/sec (unless specified "midwall" all SV are corner vibrations).
GV = Ground vibration.
Max.H = Maximum horizontal component of vibration.
Vert. = Vertical component of vibration.
H_1 = Horizontal component of vibration best approximating radial.
H_2 = Horizontal component of vibration perpendicular to H_1.
VEL = Velocity exposure level (1-second integration, 1–12Hz).
TVS = True vector sum.
PVS = Pseudo vector sum.

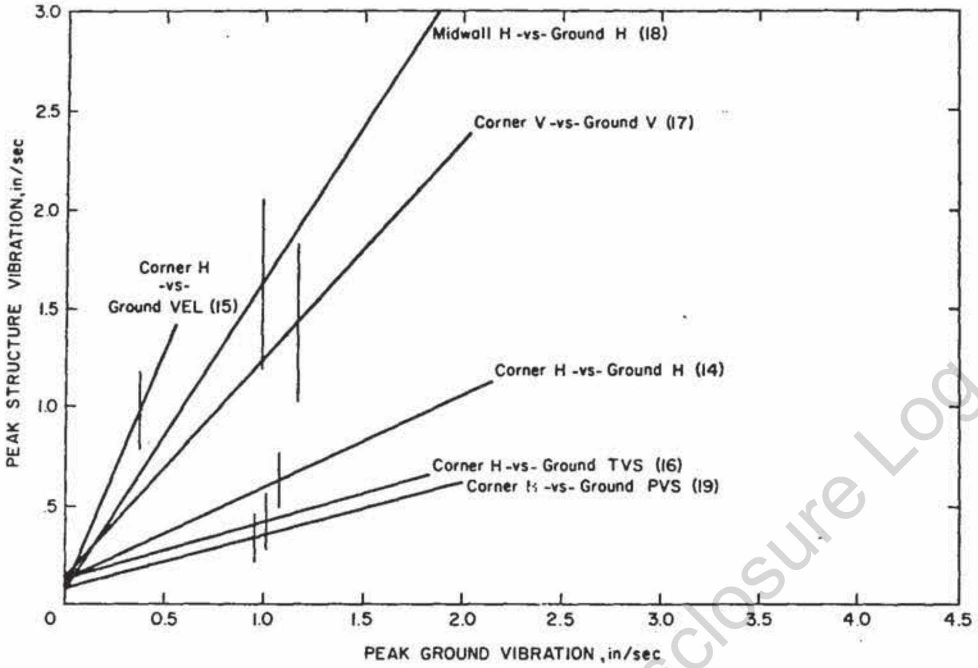

Figure 33.—Corner and midwall responses for a single structure (No. 19). Symbols, equations, and statistics are given in table 4.

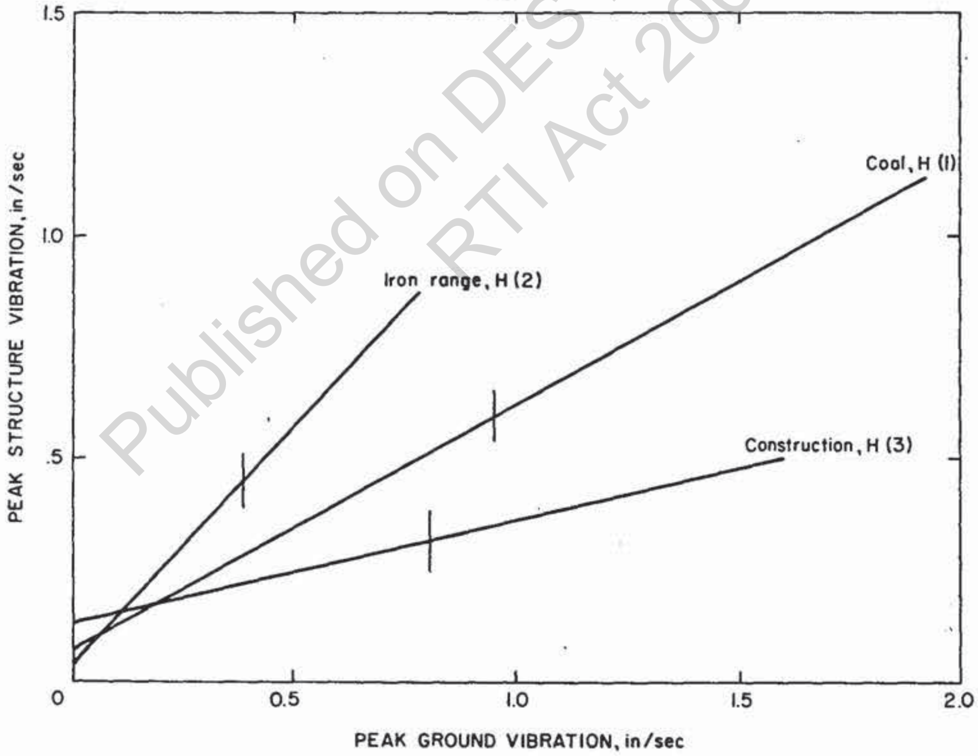

Figure 34.—Structure responses (corners) from peak horizontal ground vibrations, summary. Symbols, equations, and statistics are given in table 4.

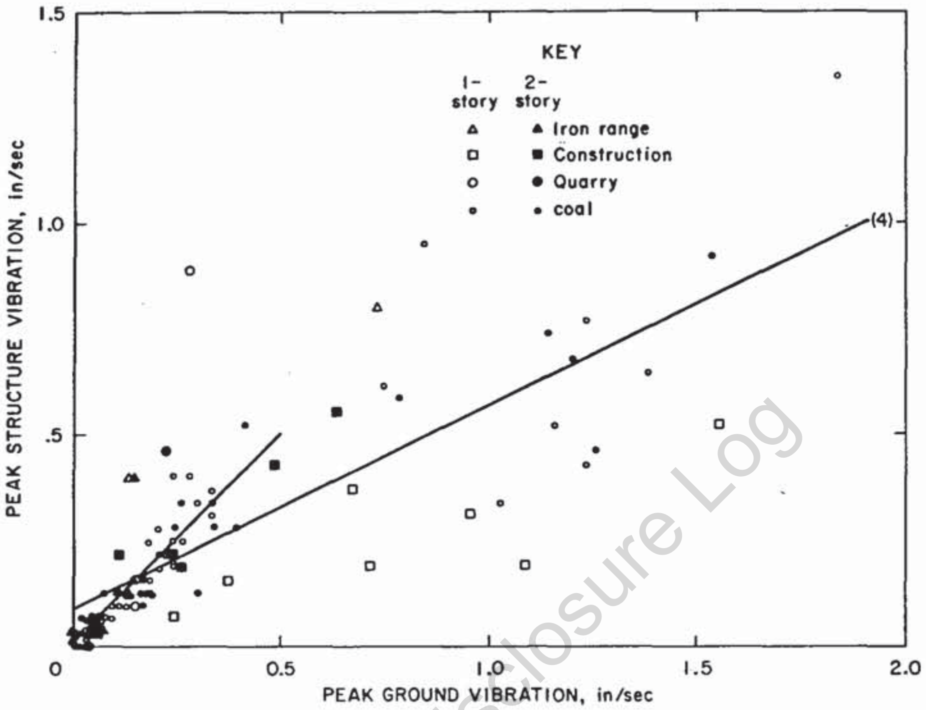

Figure 35.—Structure responses (corners) from peak horizontal ground vibrations with measured values. Equations and statistics are given in table 4.

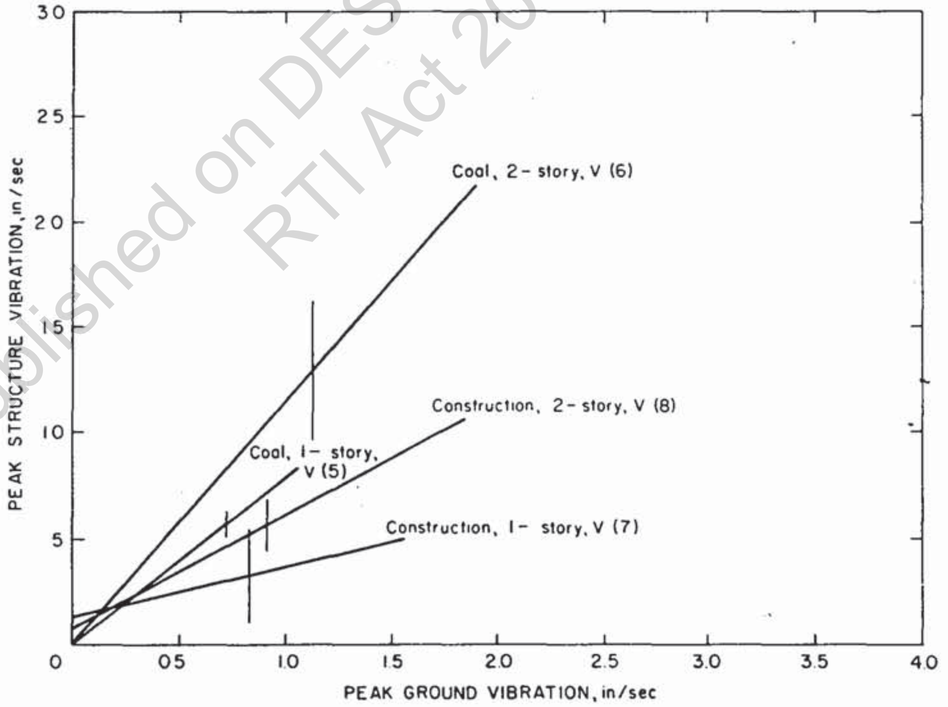

Figure 36.—Structure responses (corners) from peak vertical ground vibrations. Symbols, equations, and statistics are given in table 4.

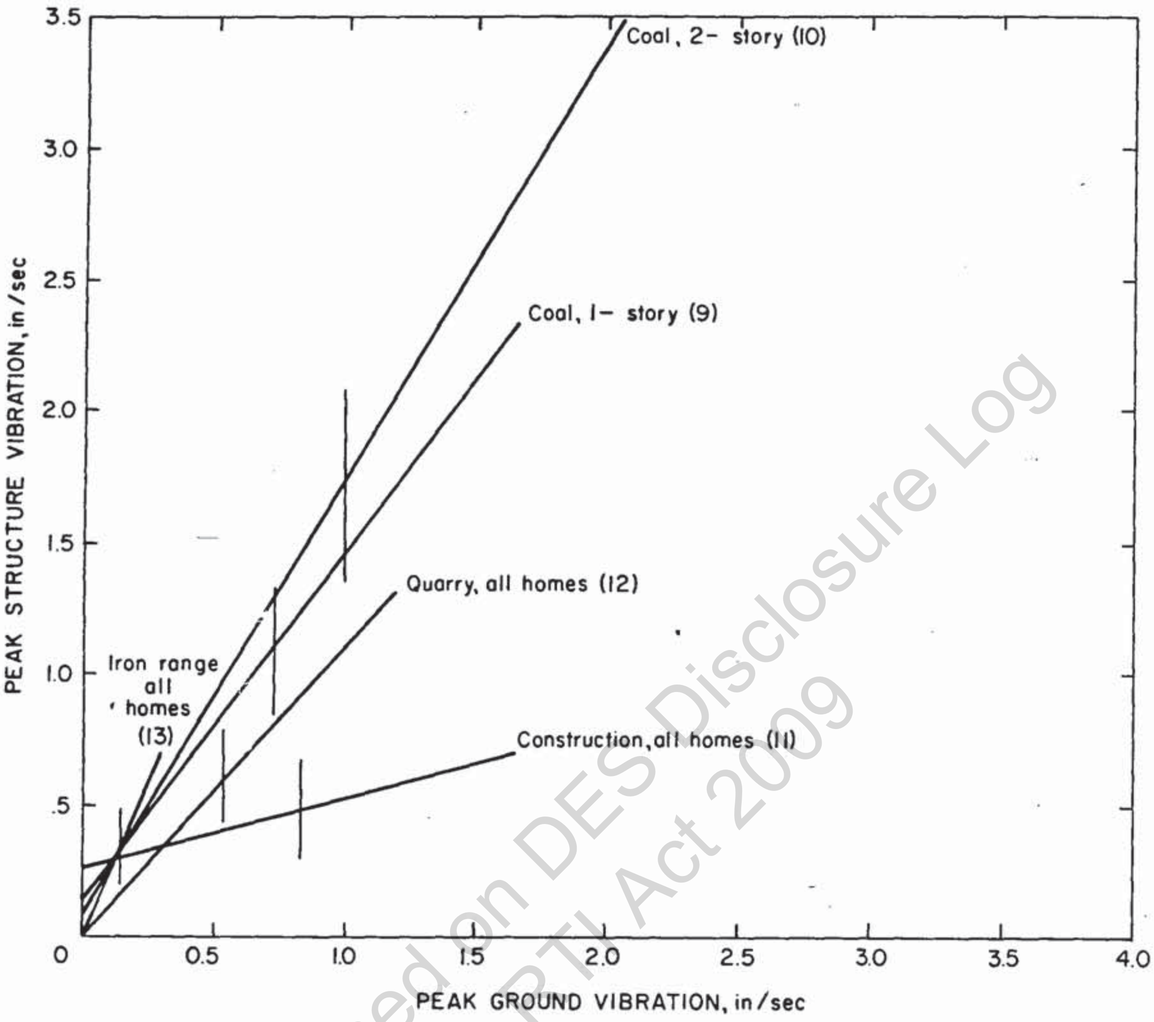

Figure 37.—Midwall responses from peak horizontal ground vibrations. Equations and statistics are given in table 4.

absolute, rather than relative, structure motions were measured, the responses at ground motion frequencies lower than the resonant frequencies theoretically should be unity; however, no ground motions with significant energy at frequencies lower than 5 Hz were encountered in this investigation. A summary of corner motion amplification factors for all of the homes studied is shown in figure 39. The highest amplifications were approximately 4, with 1.5 being a typical value. Ground motions above about 45 Hz produced little or no amplification of the corner-measured structure motion.

Midwall motion amplification factors are shown in figure 40. The maximum amplifications are greater than for the corners, with many responses occurring at higher frequencies, particularly up to 25 Hz. As with corner motions, amplification factors for ground motions above 45 Hz were less than unity.

These results suggest that frequencies below 10 Hz are most serious for potential damage from structure racking. Vibrations below about 25 Hz can excite high levels of midwall motion (typically wall motions are amplified 4 times that of the ground motions) and generate most of

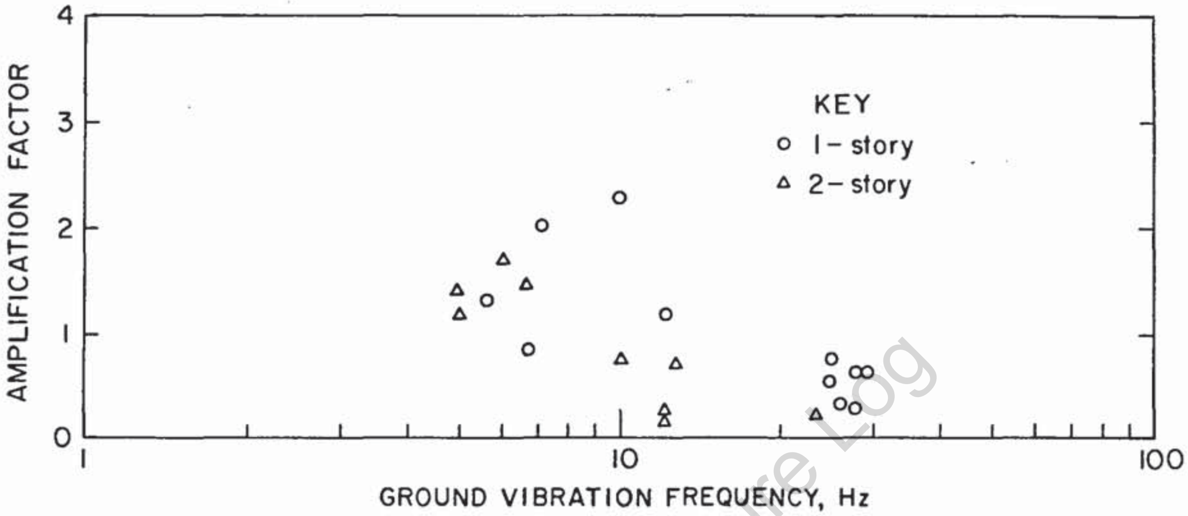

Figure 38.—Amplification factors for blast-produced structure vibration (corners) of a single 1-story and a single 2-story house.

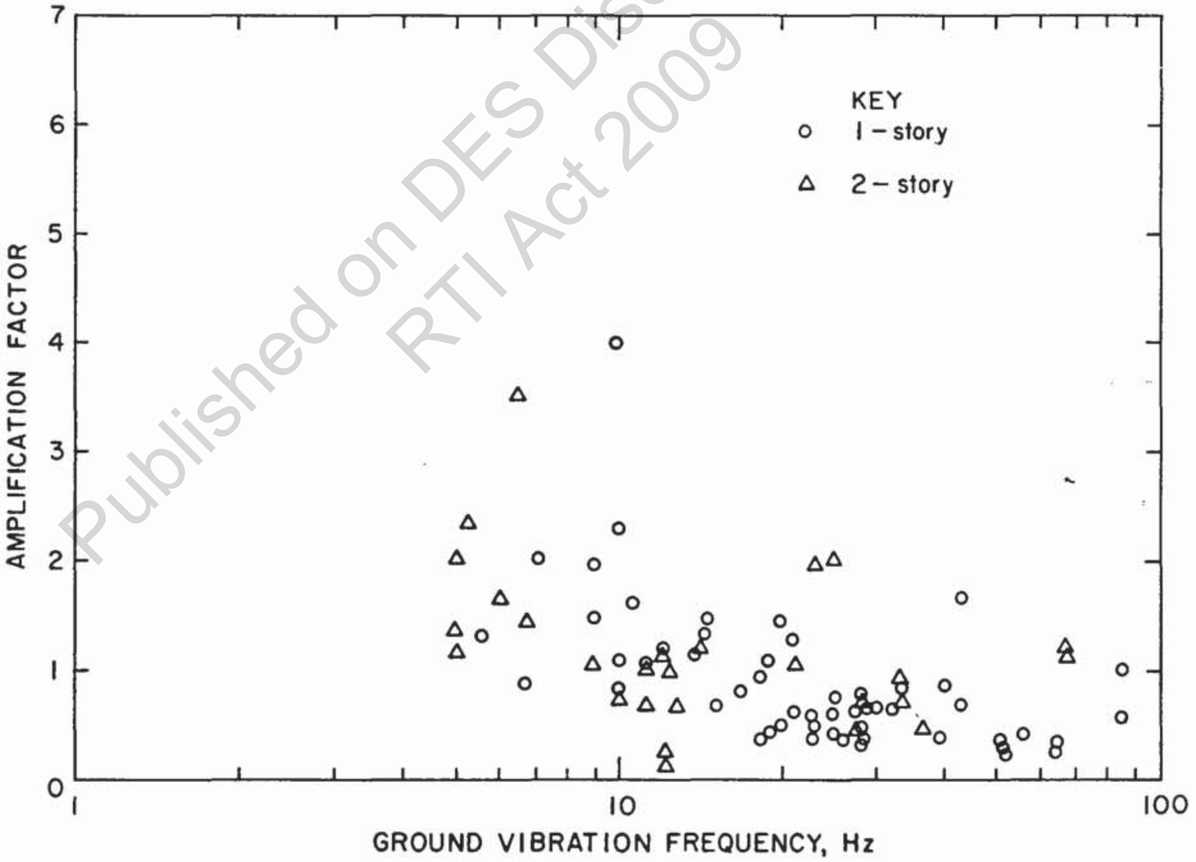

Figure 39.—Amplification factors for blast-produced structure vibration (corners), all homes.

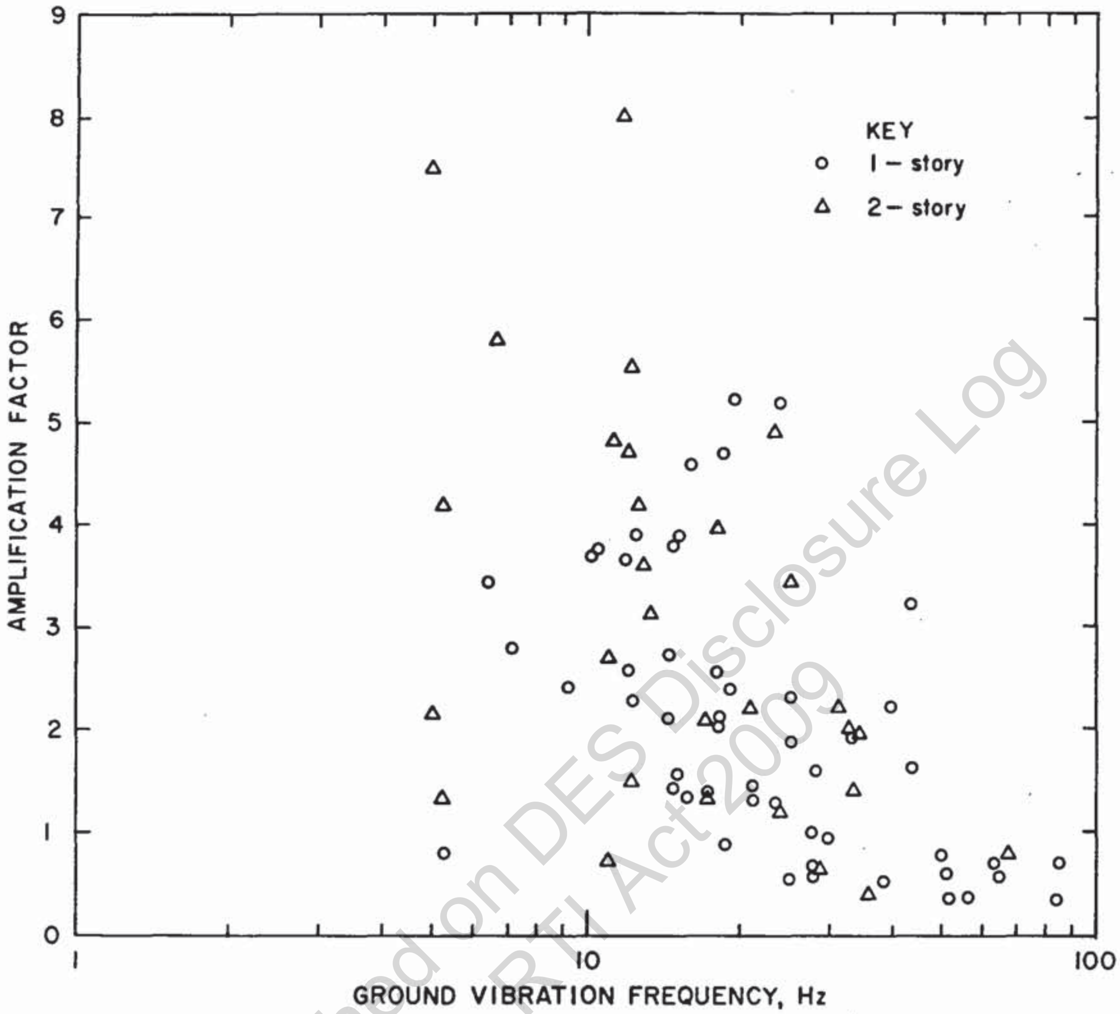

Figure 40.—Amplification factors for blast-produced midwall vibration, all homes.

the secondary noises, rattling, and other annoyances.

Kamperman studied transfer functions for residences subjected to quarry blasts (*22*). His concern was primarily with human response to midspan vertical floor motions, and an assessment of various airblast measurement descriptors. Kamperman made 23 comparisons between measured outside ground and inside floor motions from 18 blasts. He found amplification factors of 1.60 for vertical peak particle velocity and 1.04 for horizontal velocity (lateral or radial).

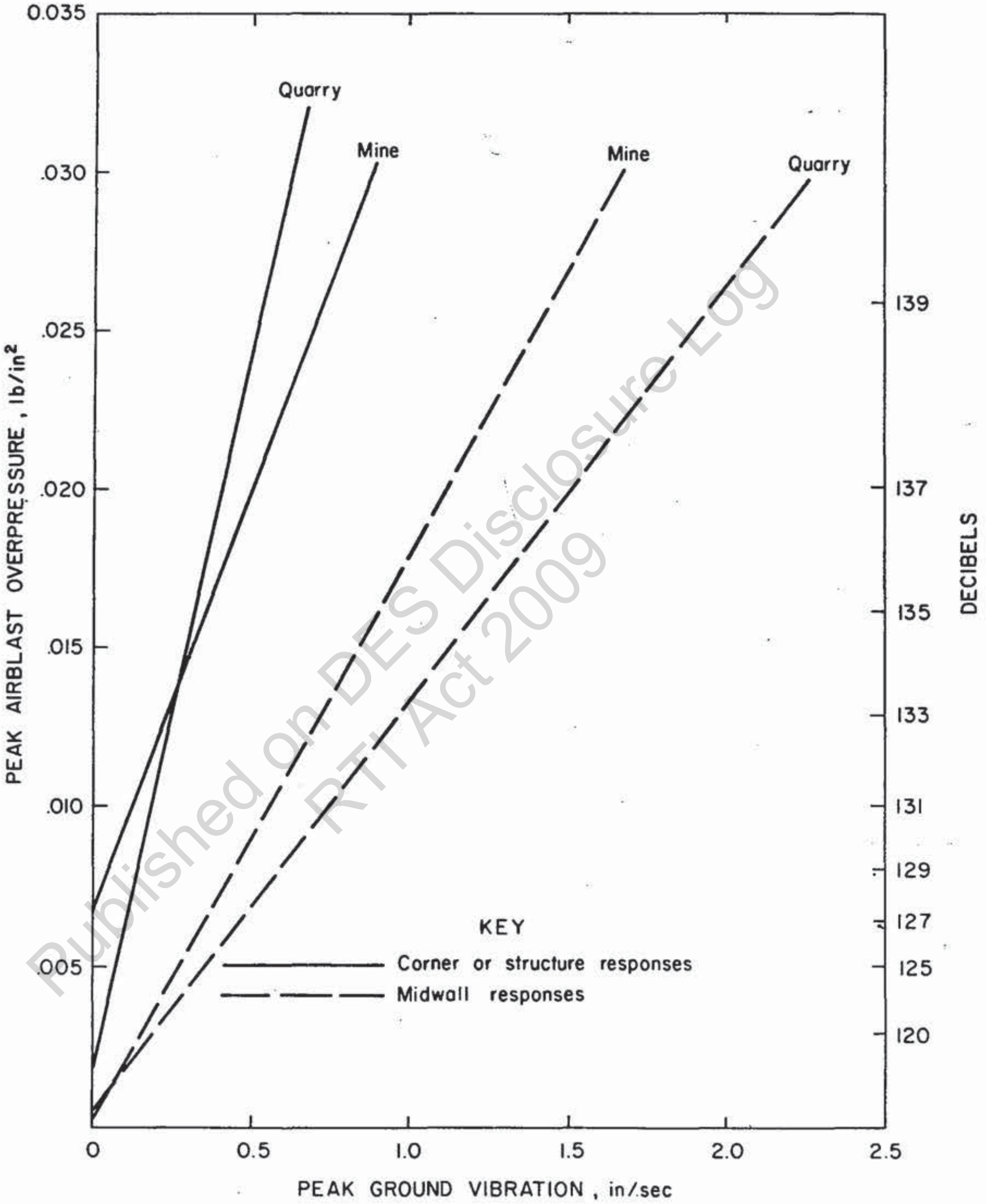

Figure 41.—Ground vibration and airblast that produce equivalent amounts of structure response, in frame residential structures of up to 2 stories.

Figure 42.—Test residential fatigue structure near surface coal mine. AYRSHIRE

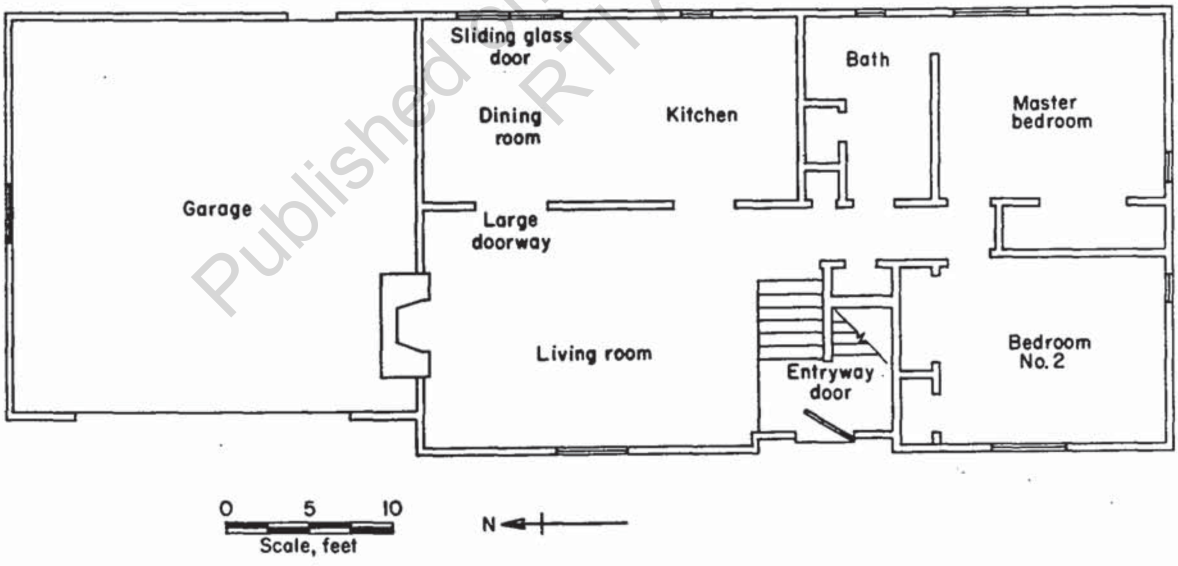

Figure 43.—Plan of main floor of test fatigue structure shown in figure 42.

Airblast Response

Structure responses from airblasts and sonic booms have been described in an extensive analysis of airblast from surface mine blasting (*46*). Levels of ground vibration and airblast that produce the equivalent structure motions are shown in figure 41, based on mean observed responses. The airblasts are those measured with 0.1-Hz low-frequency response systems. Typical 2- and 5-Hz commercial systems would give airblasts with sound levels in the range of 1 to 5 dB lower. Airblasts are relatively strong sources of midwall vibrations and poor sources of corner (whole-structure racking) vibration. The airblast levels producing the same amounts of corner vibration as 0.50 in/sec ground vibration are 0.020 to 0.024 lb/in^2 (137 to 138 dB). Relatively strong midwall vibrations are produced by airblasts, with only 0.007 to 0.009 lb/in^2 (128 to 130 dB) required to produce wall vibration equivalent to that from 0.50 in/sec ground vibration. From these equivalencies, airblast appears less likely to crack walls than ground vibration, as cracking occurs predominantly from shear and tensile wall strains that are produced by shearing rather than bending. Airblasts, however, are often responsible for the secondary rattling and annoyance effects produced by midwall motions (perpendicular to the planes of the wall surface).

Differences between mine and quarry blast-produced corner responses are not significant in the critical airblast range of 0.010 to 0.016 lb/in^2 (131 to 135 dB). By contrast, the midwall responses are very much different, probably because the relatively less confined quarry blasts produce more and higher frequency airblasts.

Structure Responses From Everyday Activities

Houses are subjected to a variety of vibrations and strains from human-produced transients and from slower processes of settlement from soil consolidation and changes in both the house and ground from natural environmental influences. The Bureau of Mines has measured strain and vibration from both human activities and from five mine blasts as the beginning of a study on fatigue effects in a residential structure.

The test structure and plan view are shown in figures 42 and 43. Strains were measured at critical places over windows and doorways using gages developed from a Northwestern University model (*11*). The maximums of the three strains measured at each location are given in table 5. The maximum principal strains would be slightly greater. Vibrations were measured in low and high corners, midfloors, and midwalls for both the blasts and the other activities (table 6).

Surprisingly high levels of strain and vibration were generated by the human activities. Comparisons between the blast- and human-produced effects suggests that house superstructures are continuously subjected to transients producing localized strains equivalent to ground vibrations of up to 0.50 in/sec. Additionally, it was found that effects produced in one part of the house (i.e., a front door slam) could produce significant strains all over the structure. No measurements have yet been made on the masonry facade or the basement floor or walls.

Table 5.—Strains in fatigue test structure from blasting and human activity

Strain locations	Maximum structure strains, μin/in						
				Door slams			
	Mine blasts	Jumps	Heel drops	Entrance	Sliding glass	Nail pounding	Walking
Over sliding glass door	[1]22,[2]15	24	9.2	13	22	21	Low
Over south window in master bedroom	[3]18	42	20	12	19	9.3	9.1
Over large doorway in living room	[4]24,[5]11	17	6.1	8.3	6.2	28	Low
Over picture window	[4]33	17	11	21	3.6	32	3.2
Over entrance door	[4]36,[5]43	13	5.8	140	Low	Low	Low

[1] From peak ground vibration of 0.300 in/sec, 129 dB airblast.
[2] From peak ground vibration of 0.210 in/sec, 124 dB airblast.
[3] From peak ground vibration of 0.290 in/sec, 124 dB airblast.
[4] From peak ground vibration of 0.470 in/sec, ~~117~~ dB airblast. 119
[5] From peak ground vibration of 0.320 in/sec, 125 dB airblast.

Table 6.—Structure vibrations in test fatigue structure from blasting and human activity

Vibration location	Mine blasts	Maximum structure vibrations, in/sec					
		Jumps	Heel drops	Door slams		Nail hammering	Walking
				Entrance	Sliding glass		
NW corner, low horizontal living room	[1]0.~~472~~ .377 [2].483	0.190	0.055	0.220	0.110	0.100	0.056
NW corner, low vertical living room	—	.200	.069	.120	.041	.180	.180
NW corner, high horizontal living room	[1].316 [2].345	.170	.037	.260	.100	.064	.054
SE corner, low horizontal master bedroom	[3].227 [4].222	.310	.139	.182	.164	.508	.157
SE corner, low vertical master bedroom	[5]~~.392~~ .314 [3].194	.286	.133	.121	.029	.118	.126
Midsouth wall, master bedroom	[5].508 [4].700	1.44	.783	1.29	.136	.241	.225
Mideast wall, master bedroom	—	2.63	1.42	.934	.111	3.81	.285
Midwest wall, living room	[1].964 [2]1.37	1.00	.486	1.05	.124	.365	.086
Midfloor, [illegible] room	—	5.58	4.08	1.25	.031	.063	1.49
Midfloor, living room	[1]1.18 [2].85	10.1	5.84	.453	.272	.067	.286

[1] From peak ground vibration of 0.470 in/sec, ~~117~~ dB airblast. 119
[2] From peak ground vibration of 0.320 in/sec, 125 dB airblast.
[3] From peak ground vibration of 0.210 in/sec, 124 dB airblast.
[4] From peak ground vibration of 0.300 in/sec, 129 dB airblast.
[5] From peak ground vibration of 0.290 in/sec, 124 dB airblast.

FAILURE CHARACTERISTICS OF BUILDING MATERIALS

Most of the damage concern from the relatively low-level blasting vibrations involves cosmetic cracking of the interior walls of residences. Modern construction uses interior walls of gypsum plaster board (Drywall) with a covering of paint, wallpaper, or a plaster wash. Older homes often have interior walls of thick plaster over wood lath support. The strength of interior construction materials is not well understood, as they are not explicitly used as shear force resisting elements and homes tend to be nonengineered structures. However, it is evident that wall coverings stiffen their responses to forces acting in the planes of the walls. Early Bureau of Standards work on the strength of construction materials is discussed by Beck (*3*).

GYPSUM WALLBOARD FAILURE

Gypsum wallboard or Drywall consists of a panel of ⅜- to ⅝-in-thick gypsum plaster with a paper laminate covering on both sides. The 0.015-in-thick paper contributes greatly to the strength of the board and conceals cracking of the plaster core.

Strength tests on gypsum wallboard and plaster are summarized in table 7. Included are tests with and without paper laminates, preloaded static, and fatigue tests for various thicknesses of boards. Initial cracking could be seen on uncovered plaster but was masked by the laminate paper on covered wallboard.

Leigh studied plaster panels subjected to simulated sonic booms (*28*). In his fatigue study, he found only one failure out of 13 panels tested, and this he attributed to the experimental design. He also performed static failure tests.

Wiss measured strains on the walls of a home as part of his study of damage from blasting on the Mesabi Iron Range in Minnesota (*57*). His is the only failure strain measured under field blasting conditions. Wiss related his measured strains to peak ground particle velocities and found that 1.0 in/sec corresponded to interior strains of up to 50 µin/in, with 15 µin/in being a typical value. Drywall failure strains were also determined from laboratory tests of samples removed from the structure. Failure strains were very high but compare well with results of Bureau of Mines tensile tests on Drywall sections.

Table 7.—Failure characteristics of plaster and gypsum wallboard

Author and type for failure[1]	Strain, µin/in	Stress, lb/in²	Material	Thickness, in	Prestrain, µin/in	Cycles to failure
Leigh (*28*): Tensile	460	300	Plaster beam	NA	0	Static.
Do	365	300	Plaster panel	⅜	0	1
Do	260	200	do	⅜	0	10,000
Wiss and Nichols (*57*): Tensile	[2]1,230	[2]920	Gypsum wallboard with longitudinal section.	⅜	0	Static.
Do	[3]3,300	[3]1,460	do	⅜	0	Static.
Do	[2]1,100	[2]650	do	½	0	Static.
Do	[3]4,700	[3]1,100	do	½	0	Static.
Do	[2]840	[2]580	Gypsum wallboard with transverse section.	⅜	0	Static.
Do	[3]3,770	[3]785	do	⅜	0	Static.
Do	[2]910	[2]380	do	½	0	Static.
Do	[3]2,400	[3]580	do	½	0	Static.
Do (in situ)	1,162	NA	Gypsum wallboard	NA	NA	Blasting.
Dowding and Beck (*11*): Shear[4]	130	NA	Gypsum wallboard core with paper laminate removed.	⅝	0	Static.
Do	80	NA	do	⅜	0	1,000
Do	50	NA	do	⅜	0	18,000
Do	90	NA	do	⅝	26	330
Do	76	NA	do	⅜	26	1,900
Do	56	NA	do	⅝	26	8,500
Do	[2]340	NA	Gypsum wallboard	⅜	26	Static.
Do	[3]>1,400	NA	do	⅝	0	Static.
Bureau of Mines (this study):						
Tensile	[2]1,240	[2]175	do	⅜	0	Static.
Do	[3]3,400	[3]285	do	⅜	0	Static.
Do	[2]1,420	[2]170	do	½	0	Static.
Do	[3]3,210	[3]250	do	½	0	Static.
Do	[2]1,445	[2]140	do	⅝	0	Static.
Do	[3]3,450	[3]230	do	⅝	0	Static.
Shear	[2]3,000	[2]95	do	½	0	Static.
Do	[3]8,450	[3]136	do	½	0	Static.

NA = Not available.

[1] All laboratory tests except as noted in parentheses.

[2] Initial gypsum core failure.

[3] Ultimate failure, paper laminate damage.

[4] Beck's strains involved measurement on test sample. Others used platen displacement.

Beck sheared gypsum panels to failure, while investigating both fatigue behavior and the effects of preloading (*3, 11*). Most of his tests were on commercially cast panels from which the paper laminate had been removed. He found that after 5,000 cycles the panel would fail at about half the maximum strain that corresponds to static failure. Beck also found that preloading or prestraining reduced the number of cycles required for failure and also the failure strain.

The principal failure strains for this study and the two points from Wiss' study are plotted in figure 44, along with observed static failure levels. Large variances are shown for Drywall core failures (e.g., 340 to 1,200 µin/in), which can be attributed to experimental load setup, moisture differences, and method of strain determination. Additional fatigue testing of building materials is needed.

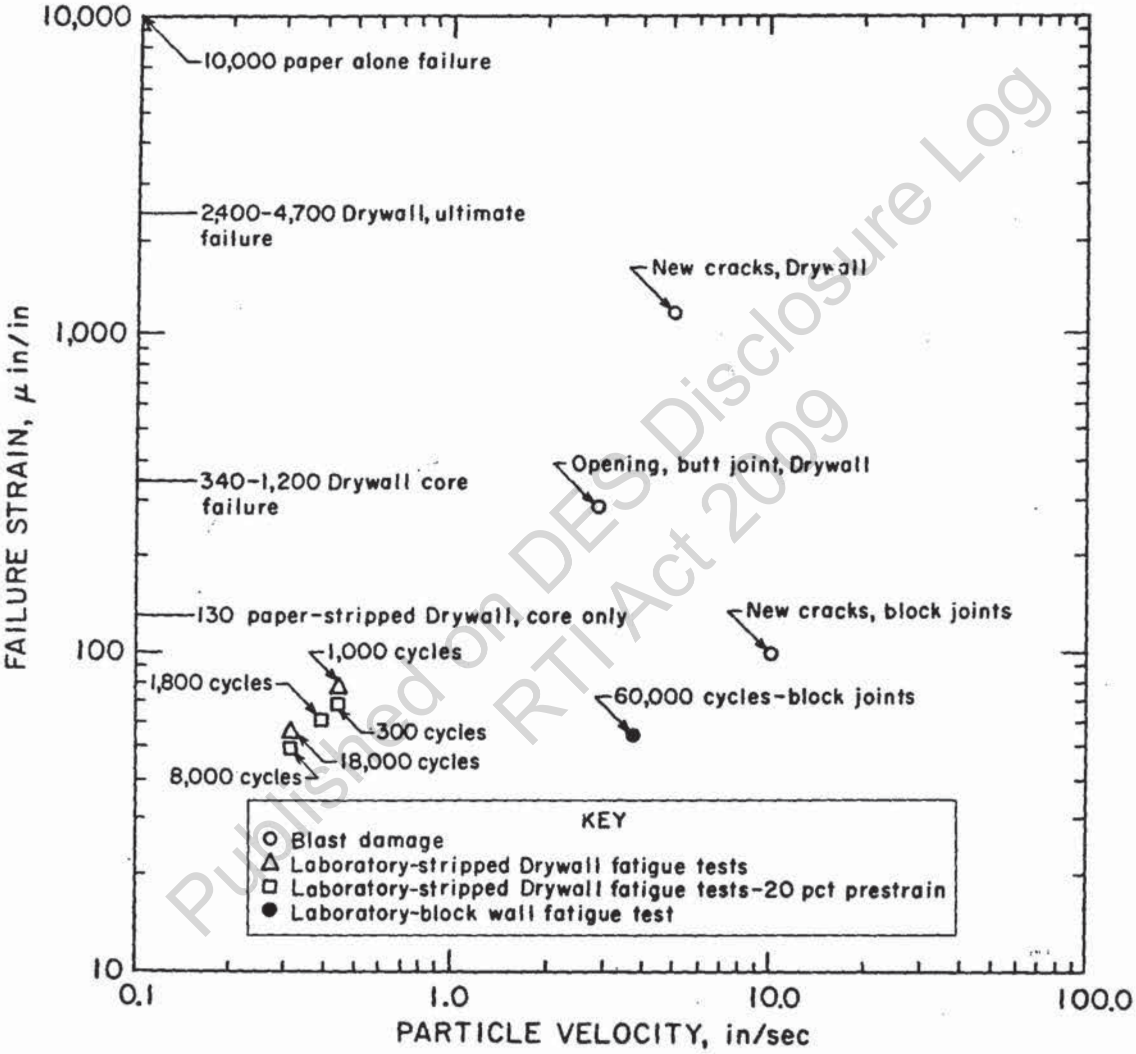

Figure 44.—Failure strains for residential construction materials from a variety of sources (tables 7 and 8).

The ultimate tensile failure strain for typical gypsum wallboard appears to be about 1,000 µin/in (*57*). Assuming that a stress concentration of 10 corresponds to the space above doorways or large windows, a shear deformation producing a uniform 100 µin/in would be potentially damaging. Projecting this over a typical house wall length (30 ft) gives peak differential displacements of approximately 0.036 in.

Complicating comparisons between different studies is that some measurements are made directly on the test specimens, while others are made using the machine platens. These values can differ by a wide margin.

MASONRY AND CONCRETE FAILURE

The two Canadian studies of blasting vibration damage included measurements of strains in basement walls of thick stone and mortar (table 8). Edwards and Northwood (*16*) found dynamic strains corresponding to initial cracking of > 375 µin/in and permanent induced strains of > 150 µin/in. Later measurements by Northwood found very much lower cracking thresholds of 45 µin/in (*38*).

Crawford and Ward studied masonry cracking induced by blasts in an 8- by 8-foot block and poured concrete box filled with sand (*9*). They found that poured concrete walls were much stronger than block walls and required high levels of both strain and particle velocity to induce cracking. The mortar joints of the concrete block wall failed at considerably lower strains, but the blocks themselves had the same ratio of strain to velocity as the concrete walls. The walls of concrete block and mortar did not act as monolithic bodies but as concentrated strains at the mortar joints. Crawford and Ward measured strain levels across the mortar joints that were 10 times those on the adjacent blocks (*9*).

Table 8.—Failure of masonry and concrete

Author and type of material	Dynamic strain at failure, µin/in	Particle velocity, in/sec	Type of cracking
Edwards and Northwood (*16*):			
On stone mortar basement walls, 18 to 24 in thick	375	3.1	Threshold.
Do	[1]150	3.1	Do.
Northwood, Crawford, and Edwards (*38*): On stone and mortar walls perpendicular to shot (radial)	40	3.4	None.
Do	45	4.5	Threshold.
Do	75	7	Minor.
Do	80	10	Major.
Crawford and Ward (*9*):			
8- and 10-in concrete block	30	3	Threshold.
Mortar joints	300	NAp	Do.
7- and 9-in poured concrete	100	10	Do.

NAp = Not applicable.

[1] This is permanent strain. All the remaining are dynamic.

Cracks appeared in the mortar joints when strains of 30 µin/in were measured on the blocks, consistent with Northwood's values (*38*). The strains across the joints were 300 µin/in. These results are consistent with the observations that cracks in the mortar between the blocks or bricks are the first signs of damage in masonry. Crawford and Ward recommended particle velocity as an index of damage independent of masonry type, with failure at 3 in/sec measured radially to the blasting and perpendicular to the block surface. This corresponds to surface strains of 35 to 40 µin/in on the blocks. Monolithic concrete, on the other hand, did not crack until particle velocities exceeded 10 in/sec and strains of 100 µin/in. Even then, the concrete cracked at the corners of the box. This location of cracking suggests that expanding gas pressures may have deformed the box and cracked the concrete at strain concentrations in the corners.

The measurement of strain is a useful engineering tool. It may provide the most appropriate method of assessing cracking potential for instances where locations of maximum strains can be predicted beforehand and material failure characteristics are understood.

FATIGUE

A very limited amount of work has been done on fatigue or damage from long-term repeated blasting. For engineered materials, fatigue strengths are typically a significant fraction of the ultimate strengths (e.g., 50 pct).

The U.S. Army Corps of Engineers, Civil Engineering Research Laboratory (CERL), conducted a fatigue damage test for the Bureau of Mines as the first phase of a full-scale fatigue study (*54*). An 8-foot-square by 8-foot-high test structure (model room) was built on the CERL 12- by 12-foot biaxial vibration table (fig. 45). This structure represented a typical residential room with a 7-foot doorway and two window openings. It was constructed of 2- by 4-inch wood studs and ⅜-inch-thick gypsum wallboard. Joints were taped and finished in the standard manner, with metal beads on the outside corners.

The vibration simulator that shook the base was programed with one of the horizontal components and the vertical component of an actual

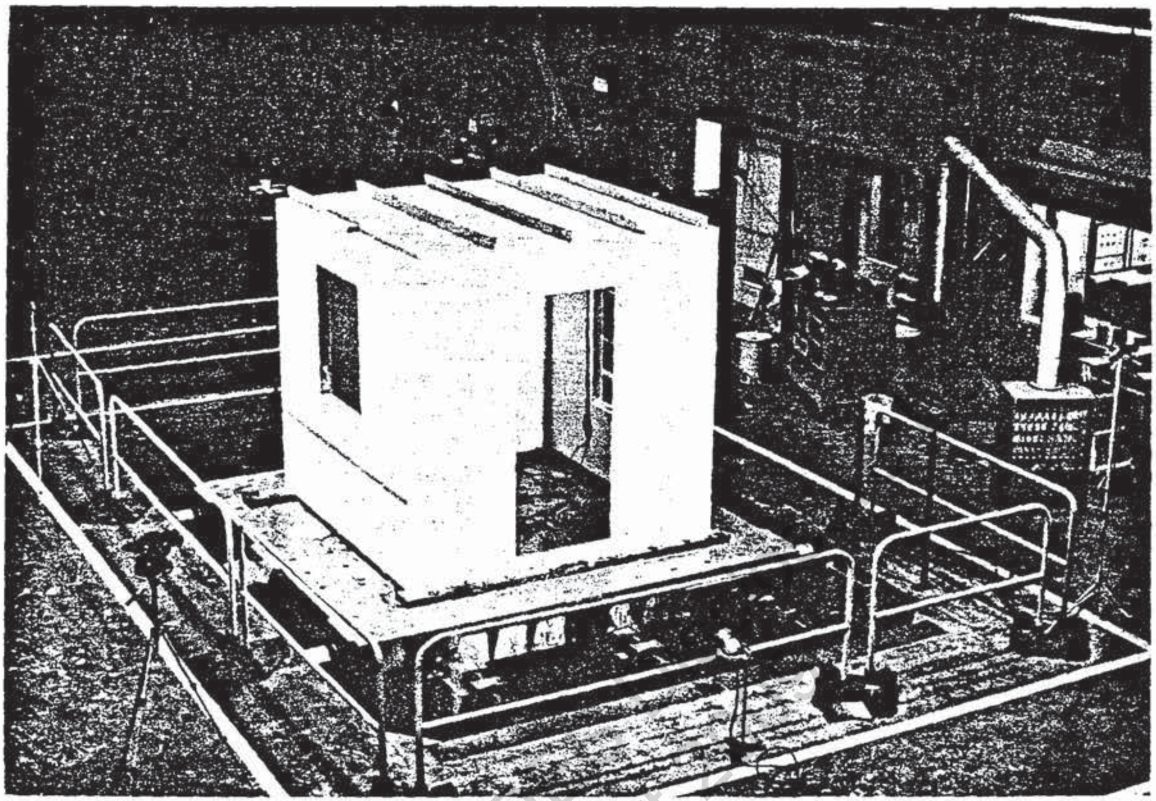

Figure 45.—Fatigue test model on biaxial vibrating table.

quarry blast from Bulletin 656 (*37*). The predominant horizontal and vertical component frequencies were 26 and 30 Hz, respectively. Testing consisted of a series of "blasts" at increasing platform vibration levels with inspections between each series. The sequence of number of events for each level of vibration was 1, 5, 10, 50, 100, and 500. The vibration levels run were 0.1, 0.5, 1.0, 2.0, 4.0, 8.0, and 16.0 in/sec. The first damage was observed after six events (blasts) at 4.0 in/sec, when the Drywall pulled away from the bottom plate. After six events at 8.0 in/sec nails began to work out, and after 66 events the corners cracked. A level of 16 in/sec produced cracks at window openings. The vibration levels from this study cannot be directly related to the full-scale case, because the excitation motions were not scaled (e.g., the natural frequency of the model was too high because the mass was too low). However, the existence of fatigue was demonstrated as each new degree of damage was observed after several complete events at that vibration level.

Fatigue and cracking of masonry walls have been studied by Koerner (*23*). He subjected 1/10-scale block masonry walls to sinusoidal vibrations at their resonant frequencies of 40 to 50 Hz. Failure was observed after approximately 10,000 cycles at peak particle velocities of 1.2 to 2.0 in/sec. More cycles were required for damage at frequencies outside of resonance. Recent tests by Koerner on 1/4-scale block walls also found fatigue effects, including the cracking of three walls at particle velocities of 1.69 to 1.95 in/sec, requiring 60,000 to 400,000 vibration cycles. Koerner predicted that the prototype natural frequency values would be half those of his model walls, and that the failure particle velocities would then be double the model results (*23*). Applied to full scale, these results correspond to more than a thousand 1-sec-long, 40-Hz events. In addition to Koerner's study, other fatigue studies are in progress to quantify the failure potentials from long-term blasting as well as the other stress-producing environmental factors.

SAFE VIBRATION LEVELS FOR RESIDENTIAL STRUCTURES

There are a large number of publications on ground vibrations and blasting; however, few contain actual observations of damage[7] and corresponding measurements of ground motions. In 1962, the Bureau of Mines published RI 5968 by Duvall and Fogelson (*14*). This was a summary analysis of the three existing blasting damage studies, one from Canada (*16*), one from Sweden (*26*), and data from Bureau of Mines Bulletin 442 dating back to 1942 (*51*). RI 5968 was revolutionary in several respects. It recommended the use of a single motion descriptor, particle velocity, in place of displacement and acceleration. Based on the use of particle velocity, a single safe value damage criterion of 2.0 in/sec was recommended, which was frequency independent over the wide range of 2.5 to over 400 Hz.

In 1971, the Bureau of Mines published Bulletin 656, a comprehensive summary of the many problems of blasting, including generation, propagation, and damage from both ground vibration and airblast (*37*). The ground vibration damage data in Bulletin 656 were those collected for RI 5968. A single new point from a study by Wiss (*57*) was included, but no new statistical analysis was conducted to include studies made since the 1962 report. It later became evident that the Bureau-recommended vibration criterion was not applicable under some conditions and that damage was occurring below 2 in/sec. Consequently, in 1974 the Bureau of Mines started a new program to examine damage from blasting. This included an analysis of data that had become available since 1962, and also the collection of new damage data, particularly from large-scale blasting operations in coal mines.

Review of the RI 5968 indicated that low-frequency vibrations (e.g., 2.5 to 40 Hz) were a significant problem and required additional study, such as response spectrum analysis. The 2.0-in/sec safe level had been based on a mixture of both high- and low-frequency damage data. Consequently, the inferred 5-pct damage probability was somewhat artificial and depended on the relative amount of each kind of data available. Using any given number of standard deviations from the mean of the high- and low-frequency data separately would give widely differing safe values for the two cases. The derivation of 2.0 in/sec as the safe level was based on 2.0 standard deviations from the 5.4-in/sec mean of all the minor damage points. Five values for minor damage were outside the 2.0 standard deviation damage envelope (at approximately 1.2, 1.36, 1.24, 0.75, and 0.32 in/sec), all from Bureau of Mines shaker tests that only approximately modeled transient blast loads (*51*). The last of these values was dropped for statistical reasons. Because 2.0 in/sec was also lower than all the individual major damage points, and because it included all actual blasting damage data, it was recommended as a boundary between damage and nondamage.

The large amount of scatter in the summary analysis at low frequencies is undoubtedly caused by the presence of structure resonances and initial strain states. The lower frequency vibrations also result in large displacements (and strains), and it is strain that ultimately produces cracking. RI 5968 had not presented sufficient data for separate analyses of the low and high frequencies because it was based upon only three studies, one of which was not blasting. Since the 1962 report, four major sets of additional data have become available, including new damage data obtained from Bureau of Mines research. Three other studies have supplied a few new damage points each, bringing the total number of relevant studies to 10 (table 9). Direct statistical treatment of the type used in RI 5968, probability analysis, and response spectra analysis were all applied to quantify blasting damage potentials.

PREVIOUS DAMAGE STUDIES

Few studies have been made that actually produced data useful for determination of thresholds and probabilities of damage. Required are actual structures near enough to blasts for damage and careful preblast and postblast inspections. All homes are cracked from natural causes, including settlement and periodic changes of humidity, temperature, and wind. Soil moisture changes are notorious for causing foundation cracks (e.g., from tree roots). The widths of old cracks change seasonally and often daily; however, the number of cracks continues to increase with age, independent of blasting.

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[7] The term "damage" is used in this report and those referenced (*14, 16, 26, 37, 51*) to refer to cracking of either interior superstructure walls or masonry. The special nature of the damage is discussed in later sections of this report (and in table 10); however, it is understood that the observed damage refers to cosmetic and superficial effects, and that the structural integrity of the homes is not being questioned here.

Table 9.—Studies of damage to residences from blasting vibrations

Study	Damage classifications	Types of damage	Overburden type	Structures studied	Distances to shots, ft	Shot sizes, lb/delay	Frequency range, Hz	Total shots	Damage observed, uniform classification: Non-damage	Threshold	Minor	Major	Instrumentation
Thoenen and Windes, Bureau of Mines (*51*).	Threshold and minor.	Plaster cracks and fall of plaster.	None	6 frame, brick, and stone, 1 to 3 story.	None	None	4–40	[1]163	103	26	34	0	Displacement.
Langefors, Westerberg, and Kihlstrom (*26*).	Minor and major.	do	Rock	NA	NA	NA[2]	48–420	105	57	0	32	16	NA.
Edwards and Northwood (*16*).	Threshold, minor, and major.	Cracks in masonry, bricks, or stone basement walls.	Soft, wet sand with clay 20 ft down, and well-consolidated glacial till.	6 total: 4 with 12-in brick and plaster interiors, 2 frame.	30–200	47–750	2.5–25	22	22	6	8	5	Displacement and acceleration measured on basement walls.
Northwood, Crawford, and Edwards (*38*).	do	Basement wall damage close in, and superstructure plus basement damage far out.	Glacial till and limestone overlain by thin till layer.	6 total: 1 frame, 1 stone, 4 9- to 12-in brick.	3–300	0.3–1,600	[3]7–120	60	51	10	4	5	Velocity, MB-120 gage, measured on basement walls.
Thoenen and Windes, Bureau of Mines (*51*).	Threshold and minor.	None	10 quarries	14 total	715–2,500	36–1,200	3–16	43	11	0	0	0	Displacement and acceleration.
Morris and Westwater (*31*).	Threshold	Plaster and partition cracks.	1 quarry and 1 surface coal mine.	2 stone with plaster interiors.	115–820	200–14,000	3.7–5.7	3	1	2	0	0	Displacement.
Dvorak (*15*)	Threshold, minor, and major.	Plaster and masonry cracks.	Semihard clay with sand lenses.	4 brick and masonry.	30–164	2.2–44	1.5–15	58	7	25	15	11	Do.
Wiss and Nicholls (*57*).	Minor	Drywall cracks	Glacial till	Single structure, rubble stone foundation.	35–200	1–85	NA	10	9	0	1	0	Velocity, MB-120 gage.
Jensen and Rietman (~~*37*~~). 21	do	do	Rock with 0 to 7 ft of soil overburden.	18 frame structures.	[4]30–185	1.75–12.75	[5]11–126	29	27	0	2	0	Do.
Bureau of Mines new data.	Threshold and minor.	Plaster, Drywall, and masonry cracks.	Various, usually with soil overburdens.	17 frame structures.	14–2,500	18–2,600	6.3–71	225	~~37~~ 76	~~23~~ 28	3	0	Do.

[1] Shaker tests.
[2] Excavation in rock, small shots.
[3] Predominantly 12 to 26 Hz for damage data.
[4] Plus 1 at 5 ft.
[5] Mostly >30 Hz.
NA = Not available.

Analysis of damage probabilities is particularly difficult because of the low probabilities being sought. For example, reliable determination of the 2-pct damage probability theoretically requires 49 nondamage measurements for every one of damage. Consequently, it is necessary to pool all the available data while avoiding the use of data that are clearly not similar to actual blasting. Examples of the latter are teleseismic blast vibrations and earthquakes, whose low-frequency content and long durations make them more likely to produce damage to structures. Thoenen and Windes' (*51*) early analyses recognized the nonapplicability of the Mercalli intensity scale developed for earthquakes, and Richter's observations on duration effects were discussed in the section on ground vibration characteristics. The shaker damage results of Thoenen and Windes are also questionably applicable, being of longer duration than actual blasting.

All the applicable blast-vibration damage studies are summarized in table 9, all involving preblast and postblast inspections. A detailed analysis of these studies is not made in this paper. Many are discussed in Bulletin 656 (*37*), and only the last two represent entirely new data. The first three studies in the table had been analyzed in RI 5968; summary results are in figure 3.4 of Bulletin 656 and figure 6 of RI 5968 (*14*). In some cases, measurements were made on foundation walls, and in others in the ground next to the structure. Obviously, uniform measurements are highly desirable. Stagg (*50*) discusses measurement methodology. The degrees of damage (threshold, minor, and major) are given in table 10.

The Canadian researchers made the second study of damage from blasting (*38*) published after RI 5968. This followed the Edwards and Northwood investigation (*16*), involved more shots and a wider range of both shot-to-house distances and shot sizes, and utilized similar experimental design.

Thoenen and Windes reported on a series of quarry blasts intended to study damage to residences (*51*). In the absence of damage, they used structure vibrators to induce cracking. The quarry nondamage data were not useful in the mean square analyses of damage thresholds performed for RI 5968; however, they are useful for probability analysis where numbers of damage and nondamage observations are compared.

Morris and Westwater described early studies on blast damage at a time when all measurements and damage criteria were based on ground displacements (*31*). In addition to discussing the Thoenen and Windes study, they describe three monitored blasts in Britain where inspections were made. They concluded that 0.040-in peak displacement would be a safe value criterion, and that a previously recommended maximum of 0.008 in had a considerable margin of safety. The damage data all involved low frequencies (3.7 to 5.7 Hz) with the 0.040-in displacement corresponding to a 1.0 in/sec particle velocity at 4 Hz, assuming simple harmonic motion. Prior to the use of particle velocity and going back to 1947, the State of Pennsylvania had a maximum safe blasting criterion of 0.030-in peak displacement for vibration frequencies below 10 Hz (*27*).

Dvorak (*15*) examined damage to masonry residences in a study published soon after RI 5968. Bulletin 656 discusses the Dvorak study, but did not include it in the summary analysis. The Bulletin raised questions about the old instrumentation used by Dvorak. It is not possible to verify the reliability or accuracy of any of the old studies, particularly those that published few of their actual data and for which the original time histories have been lost.

Recognizing the problems caused by old instrumentation, and particularly the low levels of damage observed by Dvorak, the analyses for this study were run both with and without the Dvorak data.

Table 10.—Damage classification

Uniform classification	Description of damage	Studies of blasting damage
Threshold	Loosening of paint; small plaster cracks at joints between construction elements; lengthening of old cracks.	Threshold: Dvorak (*15*); Edwards and Northwood (*16*); Northwood, Crawford, and Edwards (*38*). Minor: Thoenen and Windes (*51*).
Minor	Loosening and falling of plaster; cracks in masonry around openings near partitions; hairline to 3-mm cracks (0 to ⅛ in.); fall of loose mortar.	Minor: Dvorak (*15*); Edwards and Northwood (*16*); Northwood, Crawford, and Edwards (*38*); Jensen and Rietman (*21*); Langefors, Westerberg, and Kihlstrom (*26*). Major: Thoenen and Windes (*51*).
Major	Cracks of several mm in walls; rupture of opening vaults; structural weakening; fall of masonry, e.g., chimneys; load support ability affected.	Major: Dvorak (*15*); Edwards and Northwood (*16*); Northwood, Crawford, and Edwards (*38*); Langefors, Westerberg, and Kihlstrom (*26*).

Wiss and Nicholls (*57*) examined the blast damage characteristics of a single well-constructed residence on a soil type similar to that of the Canadian studies (*16*, *38*). Their single damage observation was from a very high particle velocity for this damage-resistant, rubblestone foundation structure with gypsum Drywall. This point was shown in the Summary of Bulletin 656 (*37*, fig. 3.8) for comparison to the other three studies.

Jensen and Rietman measured vibration effects from construction blasts for the Bureau of Mines (*21*). The goal was to collect response data for residences from small-scale excavation blasting for comparisons of the relative responses from shots of widely differing frequency character. Damage observations were also made, and the resulting values were used in this study. One shot was so close to the foundation (5 ft) that damage was caused by permanent ground strain, or inelastic effects. This value was not used in the analyses.

Two recent studies in Sweden became available too late for the analyses in this paper (*4*, *6*). They involved structures on solid rock, and their damage observations agreed with previous Swedish results (*26*). Bergling described a test of blast damage to a concrete and brick residence (*4*). Shots were in the range of 1 to 50 m distance, and the lowest level at which damage was observed was 110 mm/sec (4.33 in/sec). Bergling also discussed the strict German DIN 4150 Standards and British 117 (1970) Standards (appendix A). Bogdanoff described a house of similar construction, also directly founded on granite-gneiss bedrock (*6*). From 38 rounds at distances less than 100 m, he indicated no damage below a vertical peak particle velocity of 90 mm/sec. They concluded that 30 mm/sec was safe for this structure (and geology), since many nondamaging shots occurred at this level.

The Salmon nuclear blast generated damage and complaint data (*39*), as well as the structural responses discussed previously (*5*). The damage observed was at large distances and occurred at lower levels than those observed for blasting. Particle velocity was estimated to have been approximately 5 mm/sec in Hattiesburg, 34 km away from the blast. Complaints about damage were also very high, with 1 pct of all families complaining at particle velocities of 2 mm/sec (0.08 in/sec), and 10 pct at 10 mm/sec (0.40 in/sec). Little justification exists to applying the Salmon results to typical mine blasting. As discussed in the section on Ground Vibration Characteristics, the 90-sec-long, low-frequency wave is far more typical of earthquake ground motions than of blasting. As no preblast surveys were available, damage causation was impossible to determine.

J. F. Wall studied masonry structures in Mercury, Nev. (*53*). He tabulated rates of cracking and concluded that they were higher during times of blasting. He concluded that the nuclear blasts at 33 to 78 km, which produced peak particle velocities of 1 to 3 mm/sec, were generating 4 to 30 cracks in concrete block structures over the natural rate of 2.5 cracks/day (for all 43 structures). As in the Salmon study, there were no direct damage observations that could be attributed to the specific events. Also, as in the Salmon study, the vibration time histories were of character similar to teleseismic vibrations; that is, dispersed to long durations and dominated by low-frequency surface waves. Even if the damage observed were caused by the nuclear blasts, it provides no reliable insight into damage potentials from conventional blasts. Nelson (*36*) monitored crack widths in six of the Mercury structures. He observed that crack width changes during intervening periods (from wind, temperature, sun, and humidity variations) were larger than those attributed to the seismic events.

The Rulison 40-kiloton nuclear shot also provided damage data where the event durations (of 5.5 to 7 sec) were somewhat typical of mine or quarry blasting (*43*). Frequencies were probably again very low because of the long absolute distances. As with the other nuclear blast studies, no preblast inspections had been made and crack observations were based on postblast evaluations. Scholl's survey of five nearby towns found damage ratios of 3 to 6 pct at peak particle velocities of 0.79 to 1.07 in/sec, based only on postblast inspections. This is in fair agreement with the Bureau of Mines summary blast damage results discussed later in this report.

Scholl also studied the Handley nuclear blast and other similar events for complaints and damage (*42*). He related pseudo absolute accelerations and complaint ratios for these events of very low frequency ground motion, in the range of 0.25 to 1.5 Hz. No determinations were made of damage claim validity.

Esteves describes damage to a single concrete and tile residence near a quarry (*17*). The first damage observed was plaster cracks at 60 mm/sec (2.35 in/sec).

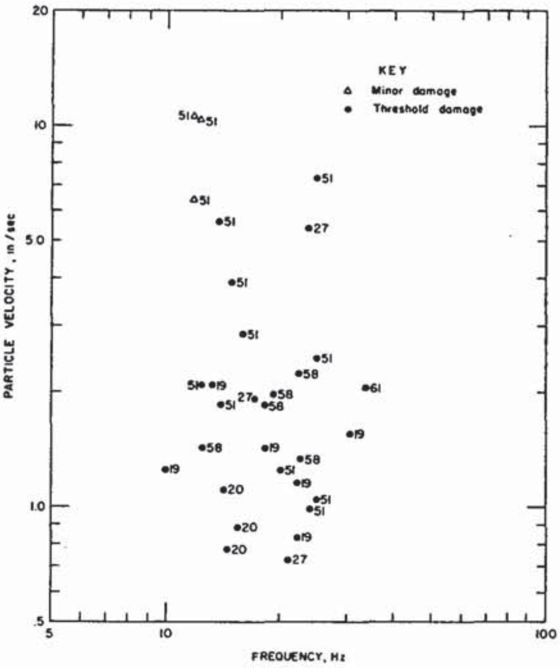

Figure 46.—Damage observations, new Bureau of Mines data from production blasting in surface mines. (Houses are listed by number in table 3.)

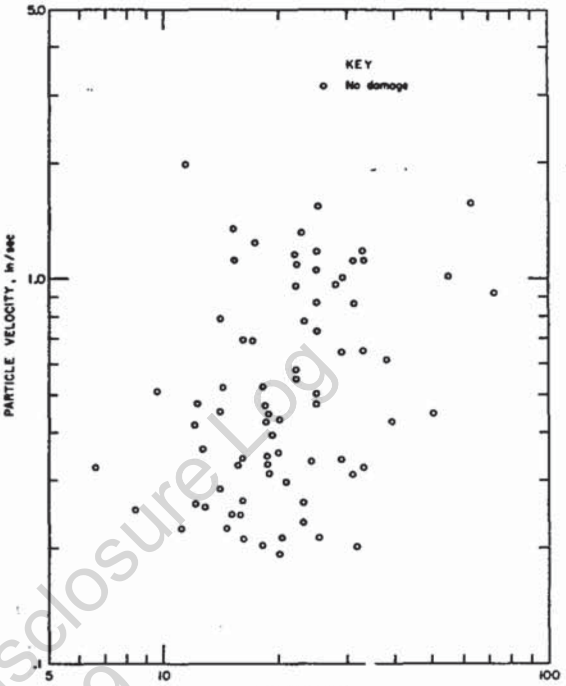

Figure 47.—Nondamage observations, new Bureau of Mines data from surface mine blasting.

NEW BUREAU OF MINES DAMAGE STUDIES

The Bureau conducted a series of field studies of ground vibration and airblast damage and responses from 1976 to 1979. Efforts were concentrated on actual measurements of wall, floor, and racking responses and the observations of damage that could be correlated to specific vibration events. A significant part of the work was done near large surface coal mines, with thick soil overburdens and large-diameter blastholes; cases of this sort had not been studied previously.

The production shots monitored for the damage analysis are listed in table 1. At five sites, houses were in the paths of the advancing mines and eventual damage was inevitable. Most of the homes, however, were not owned by the mines, and the blasts had been designed to protect them from damage. In all, 63 shots out of 225 produced useful high-level damage and nondamage data. Most of the other shots provided data on structural responses and airblast effects. Thirty-two of the shots (labeled "W" in table 1) were measured by Jensen and Rietman (*21*) under a Bureau of Mines contract. A total of 76 houses were studied (including 18 by Jensen and Rietman) and are listed in table 3. The houses that were subjected to high ground vibration levels and produced useful damage data are shown in figures 15–28.

Summaries of the damage and nondamage data from the high-level blasts are given in figures 46 and 47. Most of the damage was observed in homes with interior walls of plaster on wood lath (Nos. 19, 27, 51) and consisted of extensions of existing cracks and new hairline cracks. House 20 was notable in being a modern 1-story home with gypsumboard interior walls. Unfortunately, this structure was sold by the mine and moved before more than superficial cracking could be inflicted. The lowest level for observed damage in this structure was 0.79 in/sec (shot 48).

House 21 was also a modern 1-story residence and had been subjected to nine large blasts including six exceeding 1.0 in/sec. No damage was observed that could be correlated to specific blasts. However, this home had a significant number of cracks around windows and doors. The block basement wall on the mine side had been falling inward and was being supported by steel bracing. The foundation deformation undoubtedly contributed to the superstructure's cracking.

House 61 was also a modern 1-story structure with both gypsum wallboard and plaster interior walls. This home was subjected to a peak particle velocity of 2.23 in/sec, and several cracks propagated over windows and doors.

House 67 was also damaged (by shot W–17); however, the blast was within 5 feet and the cracking was likely produced by permanent ground strain rather than elastic energy. This shot was not considered useful for damage analysis.

Frequencies were determined directly from the vibration time histories and by real-time spectral analysis. In some cases, the records showed two dominant frequencies; high-frequency for the first few hundred milliseconds, and then a significantly longer low-frequency wave train. The values of amplitude and frequency used corresponded to the part of the vibration record that produced the larger structure response, which was invariably the low frequency (7 to 30 Hz).

Some long-term observations were made of numbers of cracks, and their widths and lengths. None of these parameters could be related quantitatively to the blasting. The number of cracks increased with time regardless of the vibration levels, and their widths varied irregularly from a variety of environmental stresses. Consequently, blast damage was assumed only when immediate preblast and postblast inspections found additional cracks or extensions.

In all cases, except three shown in figure 45, blast damage was superficial cracking of the same type as caused by natural settlement, drying of building materials (shrinkage), and variations in wind, temperature, humidity, and soil moisture. The three minor damage points in figure 46 represent cracks in masonry and large, new interior cracks exceeding 2 mm in width.

SUMMARY DAMAGE ANALYSIS

A summary analysis of damage was made using the 10 studies listed in table 9. To facilitate comparisons, a uniform classification of damage was adopted based on three levels of observed effects (table 10). The 10 studies of damage to residences from blasting produced a total of 553 observations, including 228 of various degrees of damage. These studies represent a variety of geologies, distances, and measurement methods. Data were analyzed in sets in order to group similar studies (table 11). Sets 1 and 3 were not unique enough to describe separately. Analysis involved both mean square fits and probability techniques.

Mean and Variance Analysis

The first analysis was made to determine mean and variance for the various damage classifications in terms of displacements as a function of frequency (figs. 48 to 52). This is analogous to the analyses performed for RI 5968 (*14*) and Bulletin 656 (*37*). A slope of minus 1 corresponds to a constant particle velocity, and a slope of minus 2 to a constant acceleration. A slope of zero is, of course, constant displacement.

Set 2 combines the two Canadian studies and that by Wiss, all giving similar results on glacial till. Sets 4 and 5 are the remainder of the low-frequency results with and without Dvorak's data, respectively. Set 6 is the high-frequency ground vibration data from Sweden (*26*) and from construction excavation (*21*). Set 7 is an overall summary of all the damage data.

Table 11.—Data sets used for damage analyses

Set and figures	Studies	Experimental conditions
1. (No plots)	Edwards and Northwood (*16*); Northwood, Crawford, and Edwards (*38*).	Low-frequency vibrations; glacial till soil/wallpaper on walls.
2. (Figs. 48, 53, and 55).	Edwards and Northwood (*16*); Northwood, Crawford, and Edwards (*38*); Wiss and Nicholls (*57*).	Do.
3. (No plots)	Morris and Westwater (*31*); Thoenen and Windes (*51*), quarry; Thoenen and Windes (*51*), shaker.	Low-frequency vibrations; walls stripped of wallpaper; plaster walls; shaker tests.
4. (Figs. 49 and 56).	Morris and Westwater (*31*); Thoenen and Windes (*51*), quarry; Thoenen and Windes (*51*), shaker, new Bureau of Mines (this study).	Do.
5. (Figs. 50, 53, and 57).	Dvorak (*15*); Morris and Westwater (*31*); Thoenen and Windes (*51*), quarry; Thoenen and Windes (*51*), shaker; new Bureau of Mines (this study).	As set 4 but with addition of masonry damage.
6. (Figs. 51, 53, and 58).	Jensen and Reitman (*21*); Langefors, Westerberg and Kihlstrom (*26*).	High-frequency vibrations.
7. (Figs. 52, 54, and 59).	Dvorak (*15*); Edwards and Northwood (*16*); Jensen and Reitman (*21*); Langefors, Westerberg, and Kihlstrom (*26*); Morris and Westwater (*31*); Northwood, Crawford and Edwards (*38*); Thoenen and Windes (*51*), quarry; Thoenen and Windes (*51*), shaker; new Bureau of Mines (this study).	Summary.

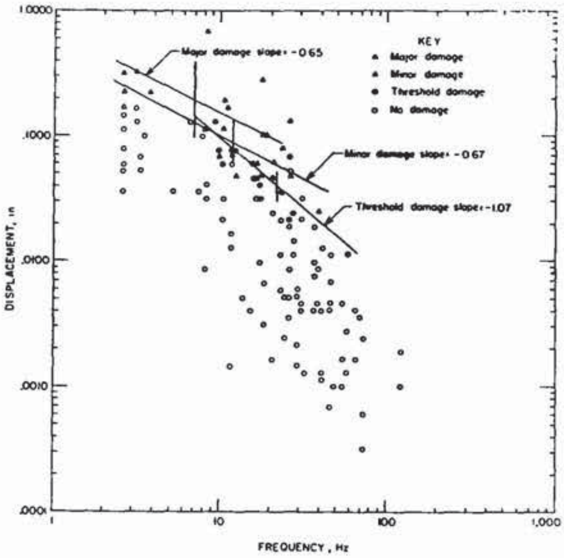

Figure 48.—Displacement versus frequency for low-frequency blasts in glacial till, set 2 mean and variance analysis.

Damage data for set 2 are shown in figure 48. The three mean regressions approximate constant particle velocities, particularly for the threshold case. All the individual damage points correspond to levels over 3 in/sec, with 2 in/sec roughly equal to three standard deviations[8] below the threshold line. The minor and threshold lines cross because of the occurrence of some minor damage at levels below some of the threshold points observed from other shots.

Set 4 analysis shows the low-frequency data, consisting mainly of the old Bureau of Mines mechanical shaker damage and new coal mine blast damage (fig. 49). All the damage points are included, even that anomalous 0.001-in displacement, 40-Hz observation from the shaker experiment (equivalent to 0.31 in/sec).

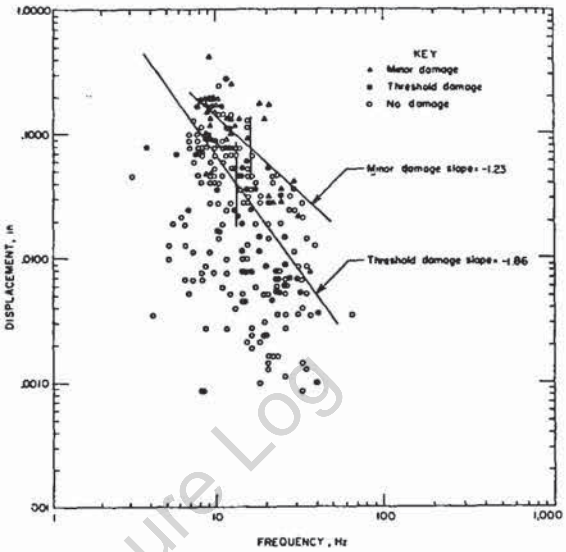

Figure 49.—Displacement versus frequency for low-frequency blasts and shaker tests, set 4 mean and variance analysis.

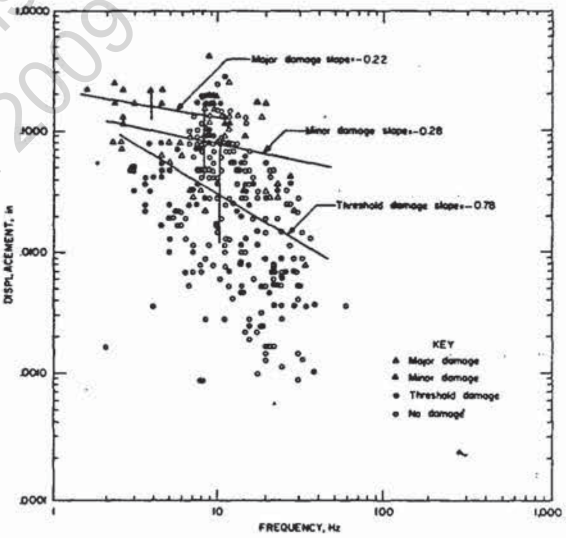

Figure 50.—Displacement versus frequency for low-frequency blasts, shaker tests, and masonry damage, set 5 mean and variance analysis.

Other than that single point, the lowest damage observed corresponded to approximately 0.72 in/sec, with quite a few points below 2 in/sec. The slopes are somewhat high, with the threshold line being almost equivalent to a constant acceleration that would have a slope of −2. The standard deviations are large, with 2

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[8] The use of these statistical techniques is based on the assumption of a Gaussian distribution about the mean square regression fit. For damage data, which have an increasing monotonic probability at increasing levels, this is not rigorously accurate. Since the observations were in categories (or degrees), the means are roughly halfway between the damage onset for that category and the onset of the next category. This makes the damage means somewhat approximate except for the open-ended "major" classification. Statistical theory puts the following probabilities on occurrences lying outside a given number of standard deviations:

Standard deviations	Total probability outside high and low limit,pct	Probability outside low limit only,pct
1	32	16
1.64	10	5.0
2	4.6	2.3
2.33	2.0	1.0
3	.4	.2

Problems involved in this type of statistical analysis were discussed in Bulletin 656 (*37*).

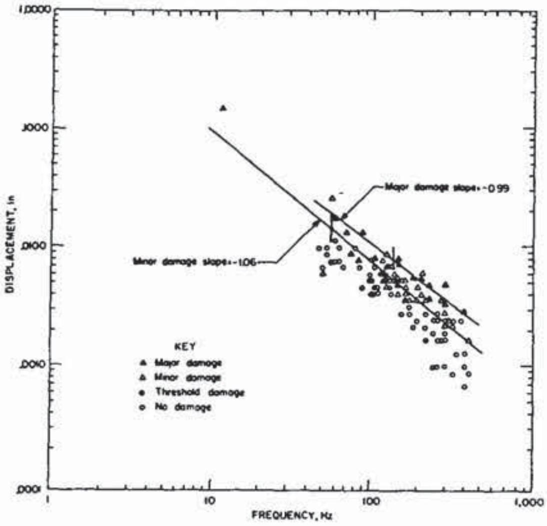

Figure 51.—Displacement versus frequency for high-frequency blasts, set 6 mean and variance analysis.

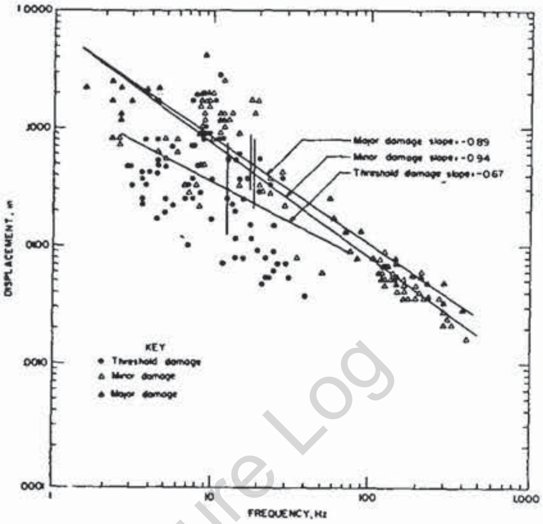

Figure 52.—Displacement versus frequency summary, set 7 mean and variance analysis.

and 3 deviations from the mean threshold giving approximately 0.7 and 0.3 in/sec, respectively.

Set 5 (fig. 50) is a rerun of set 4, but with the addition of Dvorak's data (*15*). Standard deviations increased as expected, but the slopes are reduced. The threshold line approximates a constant particle velocity of 2 in/sec, with 1 and 2 standard deviations corresponding to roughly 0.7 and 0.3 in/sec, respectively (1 standard deviation lower than the set 4 results). The lower limit of the cracking data is enveloped by the 0.51 in/sec, excluding the single maverick point. The shallow slopes suggest that these low-frequency data approximate a displacement-bound condition, which is consistent with the observation that low-frequency vibrations (e.g., 5 Hz) produce large displacements (and strains). As an example, 1 in/sec at 5 Hz is equivalent to 0.032-in displacement, which is twice the British recommended maximum of 0.016 in for vibrations below 5 Hz. The large amount of scatter in the low-frequency data is undoubtedly related to the structure response frequencies being in the same range. Between 4 and 25 Hz, the response, hence the damage for any given structure, will depend strongly on frequency. Therefore, the large amount of scatter is to be expected in a summary involving many shots and structures.

The high-frequency damage cases are shown by set 6 analysis (fig. 51), with the observation of only two classes of damage. Most notable are the minus 1 slopes (constant particle velocities), small scatter, and relatively high vibration levels for damage. No damage was observed below 2 in/sec. This level also corresponds to >3 standard deviations from the minor damage mean (lowest class of damage observed).

Set 7 (fig. 52) is an overall summary of all the damage data. The nondamage points have been omitted for clarity. This figure is analogous to the similar damage summaries in RI 5968 (*14*, fig. 6) and Bulletin 656 (*37*, fig. 3.4). The statistics corresponding to this summary analysis are somewhat arbitrary, being an artifact of the relative amount of high- and low-frequency data available. The large amount of scatter for the low frequencies shows that greater caution is required for equivalent damage probability as compared with that for high-frequency vibrations, those exceeding approximately 50 Hz. Regressions of the mean damage levels for the various sets have been plotted as particle velocities versus frequencies in figure 53, with the overall summary shown in figure 54. The maverick low point from figures 49 and 50 has been omitted as experimental error in the summary figures (figs. 52 and 54).

Probability Analysis

Probability analyses were also applied to the damage data as an alternative to regression analysis and were expected to produce more meaningful predictions. The number of damage observations within particle velocity intervals were plotted for the various sets of data. Four sampling methods were used on the damage and nondamage observations:

1. Simple counting of the numbers of points within an interval.
2. Smoothed sampling with variable-width particle velocity windows.
3. Assuming that every damage point excludes the possibility of higher level nondamage for that particular test with the reverse for nondamage.
4. Using only damage points and accumulated damage at increasing levels, and the same assumption for nondamage as for observation 3 above.

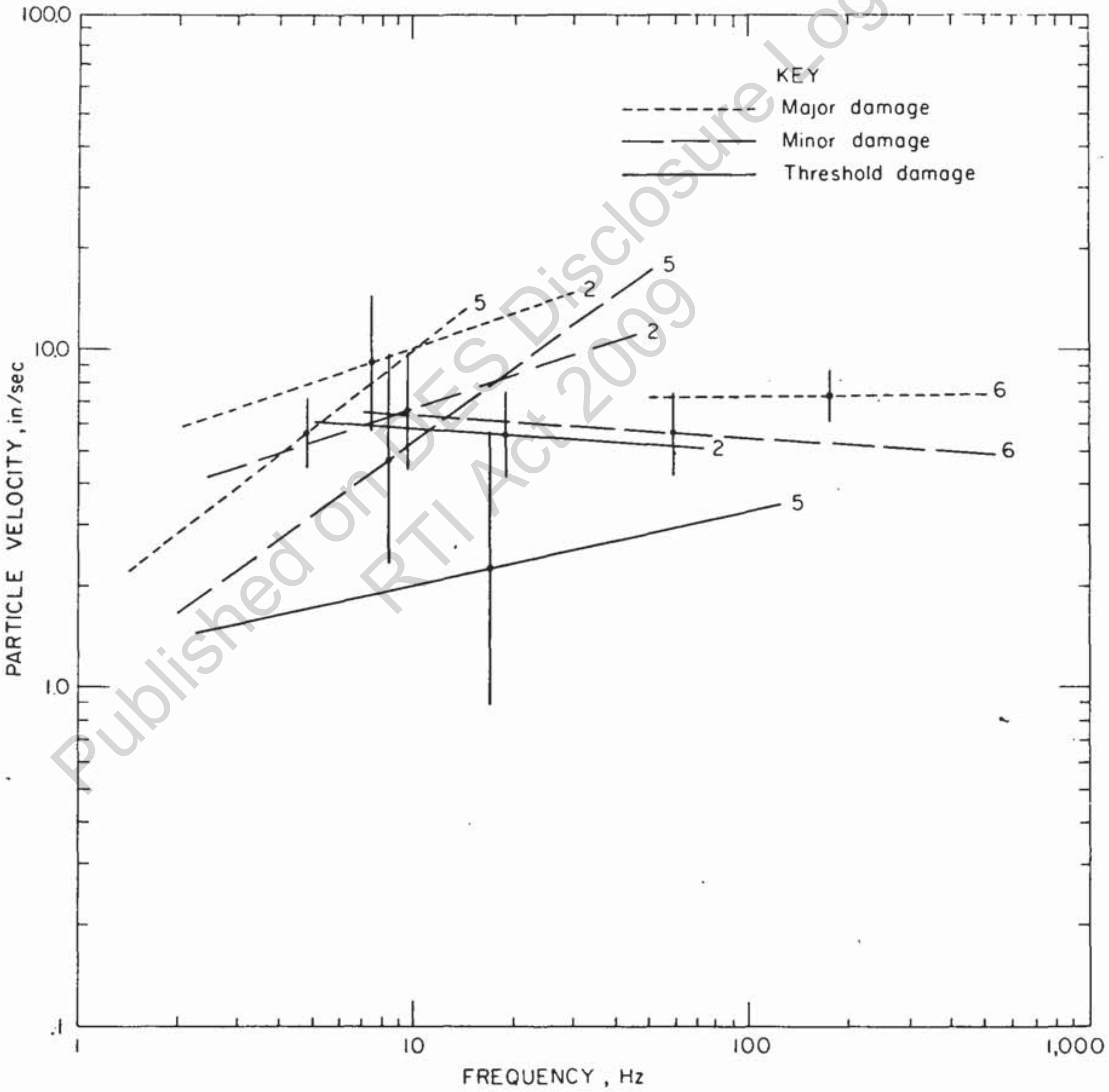

Figure 53.—Velocity versus frequency for the various damage data sets, mean and variance analysis. Sets are given in table 11.

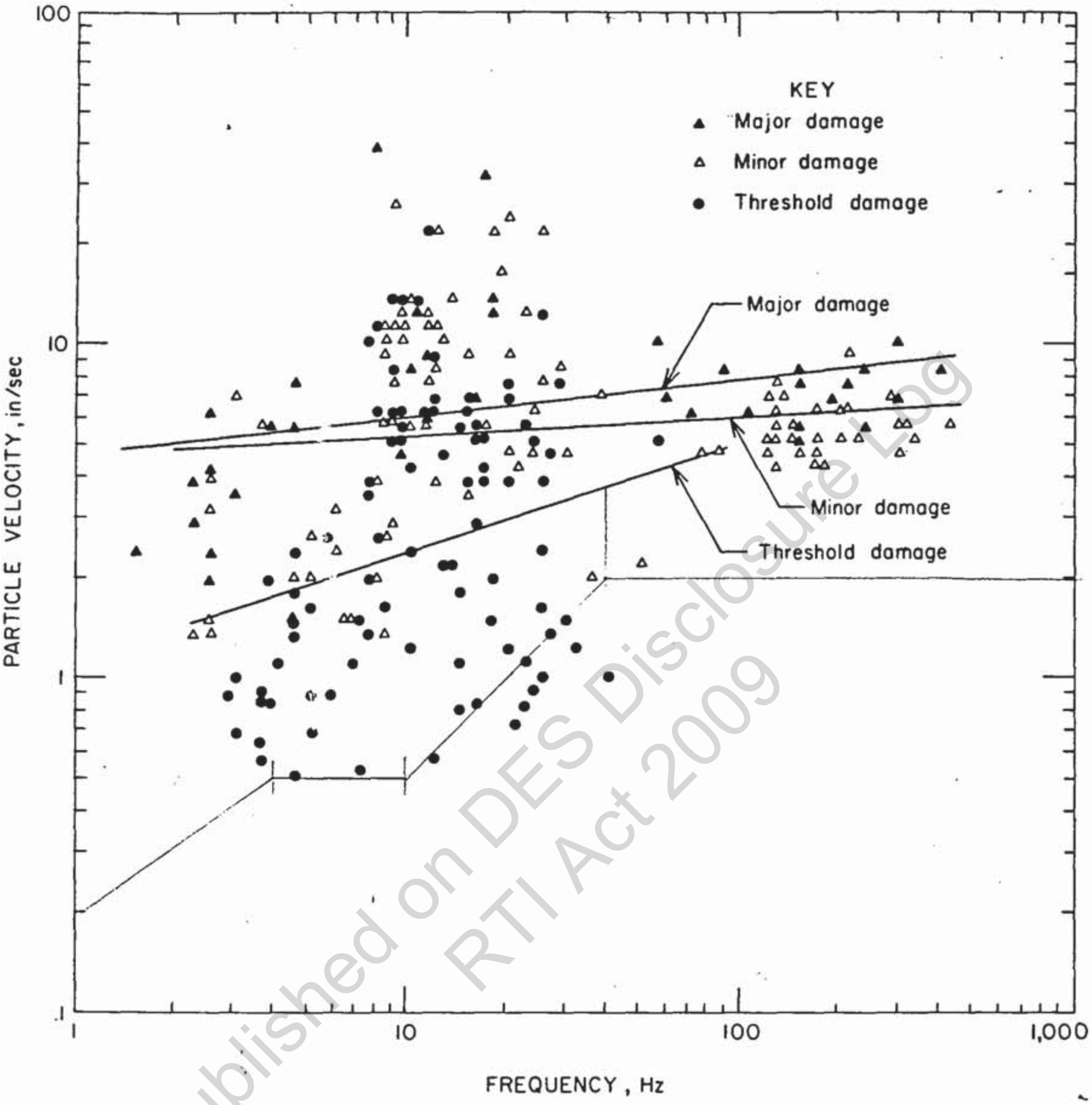

Figure 54.—Velocity versus frequency summary, set 7 mean and variance analysis.

All the sampling methods except the last violated one or more of the basic principles: (1) that the probability of damage must be independent of the sampling interval or (2) independent of the number of points (of damage or nondamage) in a given sample, and (3) that the number of new damage points must increase as levels increase. The first two principles are essential, that the probabilities concern the physics of the problem and are not a statistical artifact. The last is a result of the experimental design that involves steadily increasing levels of vibration until damage is observed. This places the observations on the upward curving part of the probability plot. When the cumulative damage was initially plotted on linear scales, they showed very little (essentially zero) damage at low levels and all damage (essentially 100 pct) at high levels. Between these extremes is the familiar S-shaped probability curve. On a log-normal ruled probability scale, the data plot as a straight line if they have the kind of log-normal distribution found for sonic boom glass breakage (*46*).

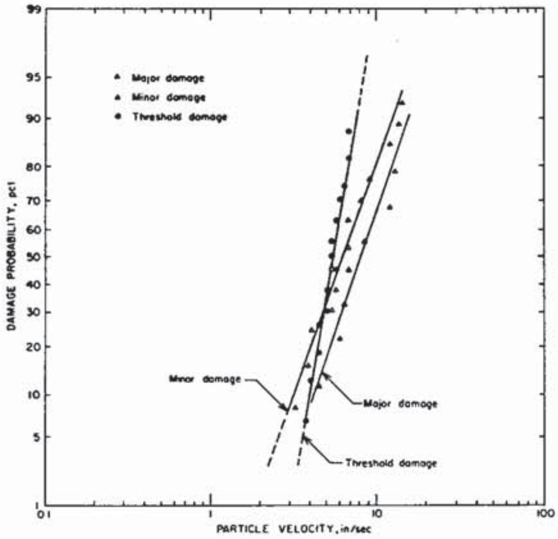

Figure 55.—Probability damage analysis for low-frequency blasts in glacial till, set 2.

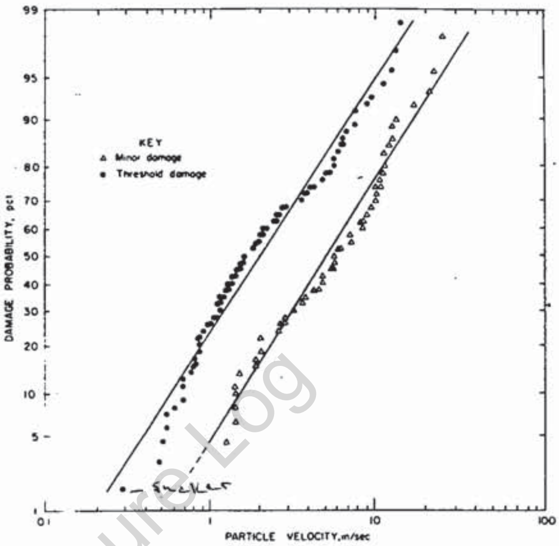

Figure 57.—Probability damage analysis for low-frequency blasts, shaker tests, and masonry damage, set 5.

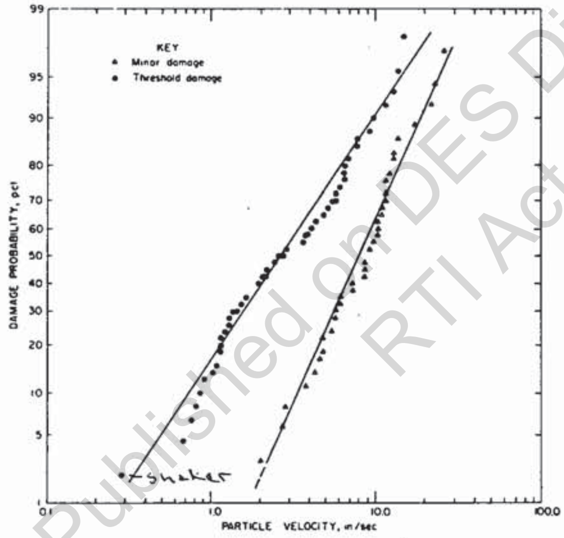

Figure 56.—Probability damage analysis for low-frequency blasts and shaker tests, set 4.

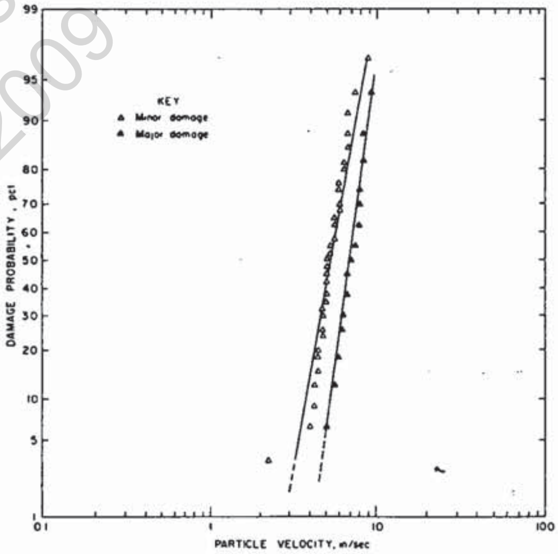

Figure 58.—Probability damage analysis for high-frequency blasts, set 6.

Log normal-scaled damage probability curves are shown in figures 55 to 59, for the same sets of studies analyzed for mean regressions. Data from the individual studies plotted as good straight-line fits, and even combining studies with apparent experimental differences still yielded high correlation coefficients.

The set 2 damage probabilities are shown in figure 55. This is primarily the two Canadian studies (*16*, *38*), and as with the analysis of mean and variance, the threshold and minor damage lines cross. Projection of the probability lines for these data shows a low probability of damage below 2.0 in/sec (2 pct or less).

Sets 4 and 5 are shown in figures 56 and 57, respectively. These are again the low-frequency damage cases and the early Bureau of Mines shaker data. Set 5 includes Dvorak's study (*15*).

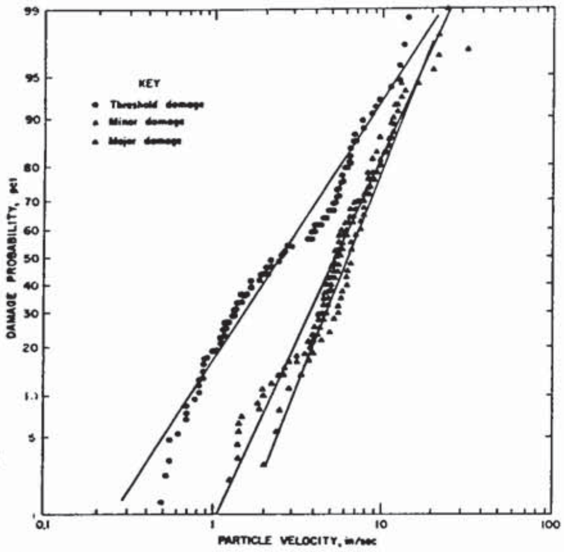

Figure 59.—Probability damage analysis summary, set 7.

The single very low valued maverick point is still included, and it produces the apparent discontinuity at the lowest vibration level. For both sets 4 and 5 probability plots, the mean line, and the trend from the individual points differ considerably at the lower probabilities. Statistical reliability increases results when the actual statistical points rather than the mean line is used for predictions. Consequently, the 5-pct damage probabilities from sets 4 and 5 are 0.80 and 0.53 in/sec, respectively.

The probability of damage from high-frequency vibrations is shown in figure 58 for set 6 data. By contrast to sets 4 and 5, data for set 6 form an excellent straight-line fit and have very steep slopes. The damage occurs over a narrow range of particle velocities, and as with the mean analysis of damage (fig. 51), it strongly supports the use of particle velocity. The vibration levels are again very high, exceeding approximately 2 in/sec for probabilities of 5 pct and below. The Swedish data alone would support a somewhat higher level, such as 3.5 in/sec for 5 pct and 3.0 in/sec for 1 pct.

The set 7 analysis (fig. 59) again represents the overall summary of all 10 sets of data. That single odd point was removed for the same reasons that it was dropped in the earlier analyses (*14*, *37*).

Most notable is the downward turn of the damage probabilities at low vibration levels, suggesting a departure from log-normal predictions and some kind of asymptotic probability toward zero damage. However, precise predictions at increasingly lower levels must necessarily become less reliable. Accurate probability figures require a large number of observations, and even this summary analysis does not have excess data, particularly for each of the principal experimental variables.

SAFE BLASTING LEVELS

The damage statistics from figures 48–59 are summarized in table 12. Safe vibration levels are suggested by the three sets of values, two from statistical analyses and a third from the simple observation of the lowest level at which damage occurred. The mean and variance values are of limited use, owing to several problems with the data. They show (for set 2) that minor damage is predicted at lower vibration levels than threshold damage. This is caused by the crossing of the means and different relative magnitudes of the standard deviations. They also produced particle velocity levels that are frequency dependent for cases where the slopes do not approximate minus 1 (set 4, threshold; set 5, minor and major; set 2, minor and major). For predictive purposes, the probability analysis results are more reliable. The lowest values of damage actually observed correspond quite closely to the 5-pct damage probabilities, except for the high-frequency data (set 6).

Safe vibration levels for blasting are given in table 13, being defined as levels unlikely to produce interior cracking or other damage in residences. Implicit in these values are assumptions that the structures are sited on a firm foundation, do not exceed 2 stories, and have the dimensions of typical residences, and that the vibration wave trains are not longer than a few seconds.

A minimum safe level of 0.50 in/sec for blasting was adopted from table 12 based on the probit analyses of set 5 (low-frequency shots) and set 7 (overall summary). This assumes a 5-pct probability for very superficial cracking. However, this vibration level is also lower than the lowest level in cases where damage was observed. The almost-constant particle velocities for the lower damage probabilities of 2 and 1 pct (threshold, set 7) strongly suggest that the

Table 12.—Summary of damage statistics by data sets

Type of damage[1]	Peak particle velocities, in/sec						
	Mean and variance analysis, standard deviations			Probability analysis			Envelope of lowest observed damage
	1.64(5 pct)	2.05(2 pct)	2.33(1 pct)	5 pct	2 pct	1 pct	
Threshold:							
Set 2	3.4	3.0	2.8	3.5	[2]3.2	[2]3.0	3.8
Set 4	.88	.63	.50	.70	NA	NA	.72
Set 5	.46	.31	.24	.52	.32	NA	.51
Set 7	.54	.36	.28	[3].53	[3].48	[3].46	.51
Minor:							
Set 2	3.0	2.6	2.3	[2]2.5	[2]2.1	[2]1.7	3.1
Set 4	3.0	2.3	2.0	2.5	[2]2.0	NA	2.0
Set 5	1.3	.98	.80	1.3	[2]1.0	NA	1.4
Set 6	3.3	3.0	2.8	3.1	NA	NA	2.2
Set 7	1.6	1.2	1.0	1.4	[2]1.2	[2]1.1	1.4
Major:							
Set 2	2.6	1.9	1.6	[2]3.3	[2]2.7	[2]2.4	4.5
Set 5	2.6	2.2	2.1	NA	NA	NA	2.0
Set 6	5.0	4.6	4.2	4.8	4.4	NA	5.5
Set 7	2.3	1.9	1.6	2.3	1.8	1.6	2.0

NA = Not available.

[1] No threshold analysis exists for set 6; no major analysis exists for set 4.

[2] Extrapolated line.

[3] Maverick point was deleted.

0.50-in/sec level will provide protection from blast damage in > 95 pct of the cases. The damage probabilities realistically refer to numbers of homes being affected by a given shot rather than the number of shots required to damage a single home. This results from the much wider variation of damage susceptibilities among structures with various degrees of prestrain as compared with a time-dependent susceptibility for a given structure. Additional work on fatigue and special soil and foundation types may later justify stricter criteria.

Data are insufficient for a thorough analysis of the damage potentials in structures of various construction types. However, the values in table 13 are obviously dominated by houses that are susceptible to cracking. Most of the observed damage listed in table 9 involved plaster cracking in older structures. Modern Drywall (gypsumboard) interior-walled homes are apparently more capable of withstanding vibrations, since the paper-backed wallboard is relatively stiff and nonbrittle. Only two studies specifically examined Drywall damage from blasting, Wiss' (57) and the new Bureau of Mines measurements. The lowest vibration level corresponding to very minor crack extensions was 0.79 in/sec (structure 20), and many nondamage observations were made at levels exceeding 2.0 in/sec. Consequently, there is little justification in using the conservative 0.50 in/sec or anything lower for modern construction, and in this case 0.75 in/sec is a good minimum criterion. The conservative 2.0 in/sec is justified for the high-frequency blasts, even though the 5-pct value is 3.2 in/sec. This is based on the lowest observed damage value of 2.2 in/sec and the fact that no observations were made of damage corresponding to the "threshold" criteria of the other studies. Construction and excavation blasting will often fall in this high-frequency category.

Table 13.—Safe levels of blasting vibrations for residential type structures

Type of structure	Ground vibration—peak particle velocity, in/sec	
	At low frequency[1] (<40 Hz)	At high frequency (≥40 Hz)
Modern homes, Drywall interiors	0.75	2.0
Older homes, plaster on wood lath construction for interior walls	.50	2.0

[1] All spectral peaks within 6 dB (50 pct) amplitude of the predominant frequency must be analyzed.

Estimation of the predominant frequency is still a problem. Where the wave train is simple, the period corresponding to the peak level can be directly measured. Otherwise, some kind of spectral analysis is required. Complex vibration time histories consist of a variety of frequencies and amplitudes, so a visual estimate of frequency can be misleading. Occasionally, the peak level occurs early in the wave and at a high frequency, with a long-duration wave train of somewhat lesser amplitude following. The safest approach is to consider the low-frequency part of the time history separately, and where it is below 40 Hz, use the 0.75 in/sec or 0.50 in/sec criteria. If Fourier spectral analysis is used, any spectral peak occurring below 40 Hz and within

6 dB (half amplitude) of the peak at the predominant frequency justifies the use of the lower criteria.

A more complex scheme of assessing the damage potential of blast vibrations is possible, using a combination of particle velocity and displacement (appendix B). This permits higher levels for the intermediate-frequency cases (15 to 40 Hz) but requires lower particle velocities for the lowest frequencies (< 4 Hz). The measurement complexity will make this impractical for many situations.

RESPONSE SPECTRA ANALYSIS OF DAMAGE CASES

Damaging and nondamaging blast vibration time histories were examined for single degree of freedom response by Corser (*8*). Four old houses were analyzed, Wiss' single structure (*57*) and three from the new Bureau analysis (houses 19, 27, and 51). Corser found that the shapes of the response spectra were not noticeably different for those that produced damage and for similar blasts that did not, but they had higher pseudo velocities. The response spectra were mostly displacement-bound at the lower frequencies (less than 20 Hz), which includes the range of whole-structure response frequencies. The lowest damage line was equivalent to structural displacements of roughly 0.012 to 0.014 in, consistent with the old British practice of taking special precautions where ground vibration levels exceed 0.016 in at frequencies below 5 Hz.

EXISTING STANDARDS FOR VIBRATIONS

A variety of vibration standards are in use or under consideration. They are intended to prevent damage to structures as well as to a great variety of other objects (e.g., computers), and also to control annoyance effects. Establishing safe and appropriate levels for all situations is well beyond the scope of this study. However, these blast vibration studies represent a major part of the research effort in this technical area. The results are often applied to situations far removed from cracking prediction in houses from short-duration, ground-transmitted vibrations. For this reason, existing blast vibration standards and reported vibration tolerances are presented in the section on Human Response and in appendix A.

HUMAN RESPONSE

The tolerance and reactions of humans to vibrations are important when standards are based on annoyance, interference, work proficiency, and health. Humans notice and react to blast-produced vibrations at levels that are lower than the damage thresholds. Similar problems also exist for annoyance from sonic booms and airblasts, and these are discussed in a related study of airblasts (*46*). The technical problem of quantifying responses is complicated by the simultaneous presence of both ground vibration and airblast and the many secondary effects of wall-produced window, dish, and bric-a-brac rattling. Persons inside buildings will hear and feel the predominantly 5- to 25-Hz structure midwall and midfloor response vibrations (*45*). Ground vibrations are occasionally blamed for house vibrations when long-range airblasts propagating under favorable weather conditions are responsible. The very infrasonic airblast itself cannot be heard, but the house responds as if subjected to a ground vibration.

Critical to levels of response are the vibration characteristics (duration, peak level, vibration frequency, and frequency of occurrence), reaction descriptors (startle, fright, fear of damage, sleep, or other interference), and tolerance descriptors (health and safety endangered, work or proficiency, and comfort or annoyance boundaries). Running like a thread through the already complex fabric are social, economic, and legal factors, typified by the importance of the vibration source to the Nation, community, or individuals involved. Examples are the temporary or indefinite nature of this environmental intrusion, beliefs in the inevitability of the source, and the social consciousness of the blaster (as shown by his public relations program and blast design efforts that minimize ground vibrations and airblast).

Most studies of human tolerance to vibrations have been of steady-state sources or those of relatively longer duration than typical mine, quarry, and construction blasting. In the absence of data on tolerance to impulsive vibrations, these results have been assumed to be applicable to blasting. Additionally, most useful data are from tests involving human subjects directly, when not in their homes. The duration and frequency of occurrence of the events are obviously critical. The vibration limits required for reasonable comfort from a long-term vibration source (e.g., air conditioning, machinery, building elevators, and vehicle traffic) are certainly more restrictive than for sources of short duration and infrequent occurrence.

The classical study of subjective human tolerance to vibratory motion was done by Reiher and Meister in 1931 (*40*). They subjected 15 people to 5-min duration vertical and horizontal vibrations in a variety of body positions and established levels of perception and comfort. Responses of "slightly perceptible" occcurred at 0.010 to 0.033 in/sec, and the threshold of "strongly perceptible" was 0.10 in/sec, all essentially independent of frequency over the range 4 to 25 Hz.

More recent research on the effects of vibration on man have produced results similar to those of Reiher and Meister (*2, 18, 55*). Goldman analyzed human response to steady-state vibration in the frequency range of 2 to 50 Hz (*18*). His results were converted to particle velocities and presented in Bulletin 656 (*37*, fig. 3.9), where the lines represent means within each response category. One standard deviation of the reactions was at approximately half the level of the means. Goldman's "slightly perceptible" and "strongly perceptible" (unpleasant) levels at 1.65 standard deviations (including all but 5 pct at the low end) are approximately 0.0086 and 0.074 in/sec, respectively, at 10 Hz. Taking these as thresholds, they agree quite well with Reiher and Meister's data.

Several researchers recognized that the duration of the vibration was critical to its undesirability. Most evident was that a higher level could be tolerated if the event was short. Consequently, steady-state vibration data could not be realistically applied to blasting, except for events that exceed several seconds' duration. A good example of a long event was the Salmon nuclear blast (*37, 39*). This was technically a transient; however, the 90-sec-long, low-frequency wave train produced at large distances resulted in numerous complaints (10 pct of all families at 0.40 in/sec). This duration exceeds that of any kind of mining blasts. Chang analyzed the human vibration response literature with particular attention to event durations (*7*). He noted that Reiher and Meister's responses could be multiplied by a factor of 10 for short events. Atherton studied impact- and walking-

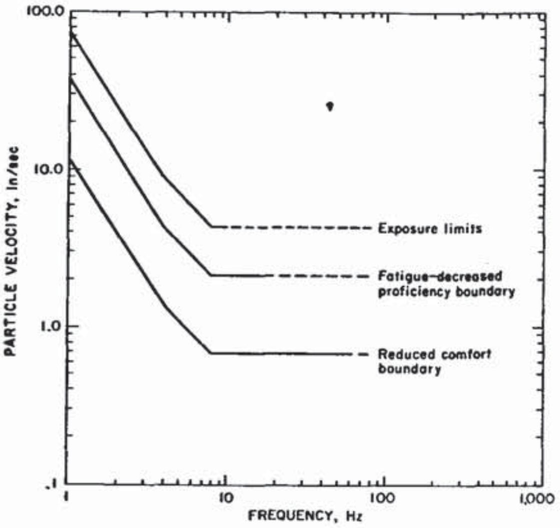

Figure 60.—Human tolerance standards for rms vibrations exceeding 1-minute-duration ISO 2631.

produced floor motions. His impact tests consisted of 3 to 5 cycles of motion at 19 Hz (the floor resonance), or events of approximately 200-msec duration. His "disturbing" level mean was 3.5 to 4.4 in/sec, or over 5 times Goldman's steady-state "intolerable" level of 0.77 in/sec at 20 Hz.

The International Standards Organization (ISO) published tolerable levels for whole body vibration in 1978 (*19*). The scope of their standard included durations of 1 min and longer, frequencies of 1 to 80 Hz, three-axis vibrations, and human tolerances for comfort, working efficiency, fatigue, and health and safety. Their recommendations for 1-min-duration events are shown in figure 60, having been converted from accelerations to particle velocities and corresponding to the worst-case body orientation (longitudinal or Z-axis). All values are rms and are constant particle velocities for frequencies above 8 Hz. Peak values would be larger by a factor of 1.4 to 3. The dashed part of the lines in figure 60 represent peak accelerations in excess of 1 g.

Wiss and Parmelee studied the responses of 40 people to transient vibrations consisting of damped 5-sec sinusoidal pulses (*58*). Damping ranged from zero to 16 pct and frequencies from 2.5 to 25 Hz. All subjects were standing on an open platform and subjected to vertical vibrations. They found that responses depended on vibration levels and damping but were independent of frequency, when plotted in units of frequency times displacement (velocity). Their results, and the two steady-state vibration studies, are shown in figure 61. The various experimental factors for the three studies are listed in table 14. The reaction descriptors were different, a sign of the subjective nature of this kind of work. "Thresholds" correspond to the responses of the most sensitive people tested. "Means" are the responses of the "average subject" within each response descriptor category. Between Goldman's "unpleasant" and "intolerable" (G–2 and G–3) lies the ISO "reduced comfort boundary". Wiss and Parmalee's results were reanalyzed for duration-of-vibration effects, with damping frequency and duration being interrelated. It was assumed that the vibration duration is the time during which the vibration level exceeds 10 pct of the peak (−20 dB). The following relationship was derived:

$$\tau = \frac{0.\text{[illegible]}67}{f\beta} + 0.018$$

where τ is the duration (sec), f the frequency (Hz), β is the damping ratio, and 0.018 the average input rise time (sec). Application of this equation to Wiss and Parmelee's test runs allows durations to be calculated for the various reactions that become slightly frequency dependent when plotted as particle velocities (fig. 62), and very much so when plotted as accelerations (fig. 63).

Table 14.–Studies of human response to vibration

Authors	Vibration duration, sec	Curve representations, response descriptors, and curve label for data plotted in figure 61
Goldman (*18*):		Mean values of subject response:
Various body positions, 5 sources	5	Perceivable (curve G–1).
Do	5	Unpleasant (curve G–2).
Do	5	Intolerable (curve G–3).
Reiher and Meister (*40*):		Thresholds:
Standing with vertical vibration	300	Barely noticeable (curve R–1).
Do	300	Objectionable (curve R–2).
Do	300	Uncomfortable (curve R–3).
Wiss and Parmalee (*58*):		Mean values of subject response:
Standing with vertical vibration	5	Barely perceptible (curve W–1).
Do[1]	5	Distinctly perceptible (curve W–2)
Do[1]	5	Strongly perceptible (curve W–3).
		Thresholds:
Do[1]	5	Barely perceptible (curve W–4).
Do[2]	5	Distinctly perceptible (curve W–5).
Do[2]	5	Strongly perceptible (curve W–6).
Do[2]	5	Severe (curve W–7).

[1] Transient with 1 pct damping. 5-sec duration is maximum.
[2] Zero damping.

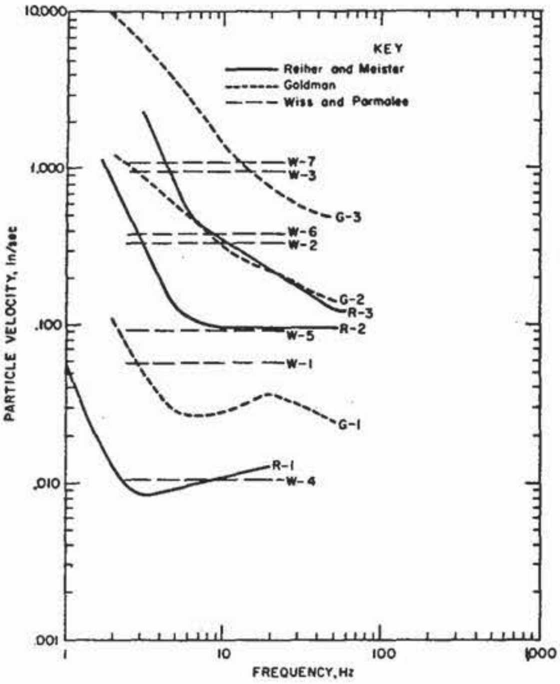

Figure 61.—Human response to steady-state and transient vibrations. Labels refer to measurements listed in table 14.

T. M. Murray investigated human reactions to vibrations of concrete floors (*33*). His summary of 91 observations of acceptable versus unacceptable cases indicated strong influences for amplitude times frequency (same units as particle velocity) and damping levels. He derived the following relationship for an acceptable concrete floor:

$$\beta \geq 35Af_0 + 2.5$$

where β is percent of critical damping (damping ratio × 100), A is initial amplitude from a heel-drop impact (in), and f_0 is the first natural frequency (Hz). Murray's data were converted to peak particle velocities and are shown in figure 64. The line represents the equation above and is Murray's eyeball separation between acceptable and unacceptable cases. Acceleration and displacement plots were also made from Murray's data and, unlike the particle velocity data, they showed a strong frequency influence.

As with Wiss' data, Murray's 91 points were converted into duration-amplitude form using the relationship:

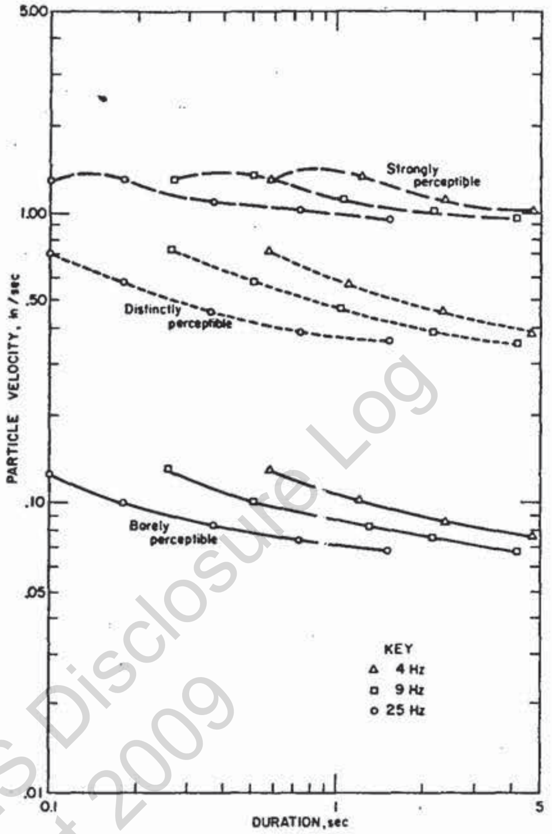

Figure 62.—Human response to transient vibration velocities of various durations.

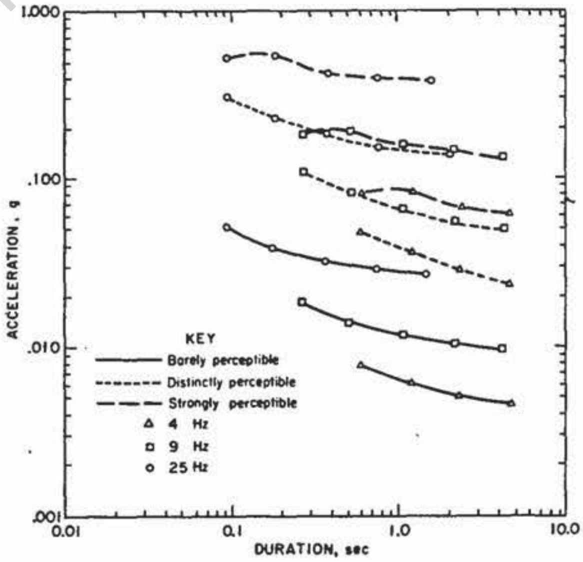

Figure 63.—Human response to transient vibration accelerations of various durations.

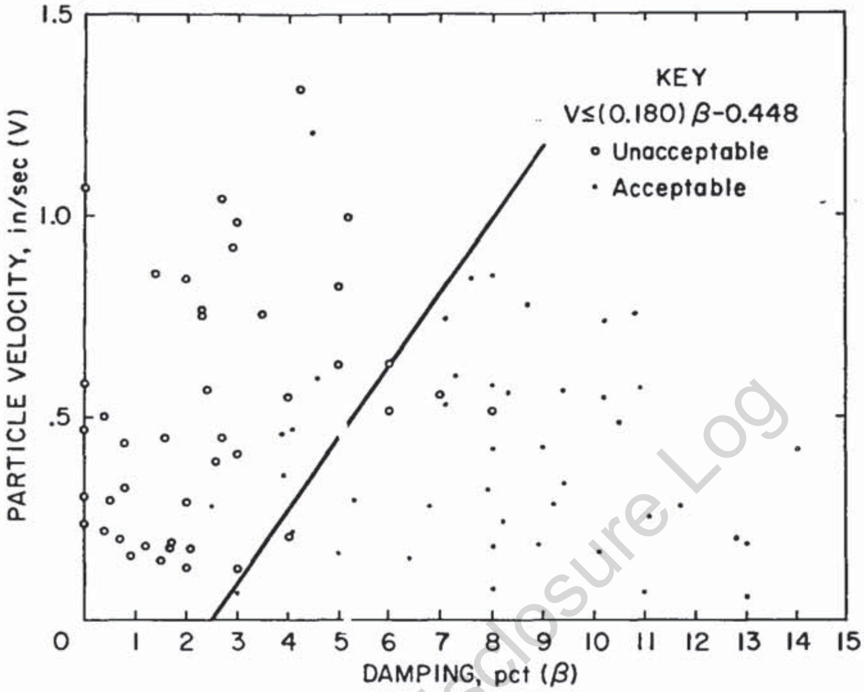

Figure 64.—Human response to vibrations of damped concrete floors, after Murray (*33*). Equation defines acceptable zone.

$$\tau = \frac{36.7}{\beta f}$$

where β is the percentage of critical damping.

The results, given in figure 65, show a strong influence on acceptability of both floor velocity and vibration duration. As in Murray's analysis, a separation of cases was derived by visual means and produced the following acceptability criterion:

$$V \leq 0.415\,\tau^{-1.29}$$

where V is the peak floor vibration (in/sec) and τ is the time (sec) from the peak to the minus 20-dB level (or 10 pct of peak amplitude). The amplitude-duration acceptability line shows a better defined separation of cases than Murray's original amplitude-damping version.

As with Murray's damping version of the data, the duration version did not produce simple relationships when plotted as accelerations and displacements, with frequency factors and nonlinear plots required. Murray suggests that his acceptability criteria for concrete floors may be conservative compared with that for wooden floors, where a greater amount of vibration is normally expected.

Human reactions to events of varying durations are summarized in figure 66, with the values given in table 15. In cases where "distinctly perceptible" applies (i.e., infrequent and short-duration events), these results suggest that levels of over 0.5 in/sec could be tolerated. The barely perceptible levels are still below 0.1 in/sec; consequently, it is impractical for blasting ever to be totally unobtrusive.

The studies just discussed all involve people in a test situation rather than in their own homes. None of the problems of damage fear, startle, house rattle, and other secondary effects were present. Undoubtedly, the addition of such effects lowers the thresholds at which people react. Relationships have been developed for people subjected to sonic booms and airblasts in their "normal" environment (*46*).

An estimate of annoyance from indoor-perceived ground vibration can be made by comparing airblast and ground vibration-produced midwall response (fig. 41), and the annoyance curves from airblast study. Estimated ground-vibration-produced human reactions are given in figure 67 based on the airblast responses from figure I–1 of RI 8485 (*46*). These are for coal mining; quarry levels are 20 pct higher. The three lines of the figure show the distribution

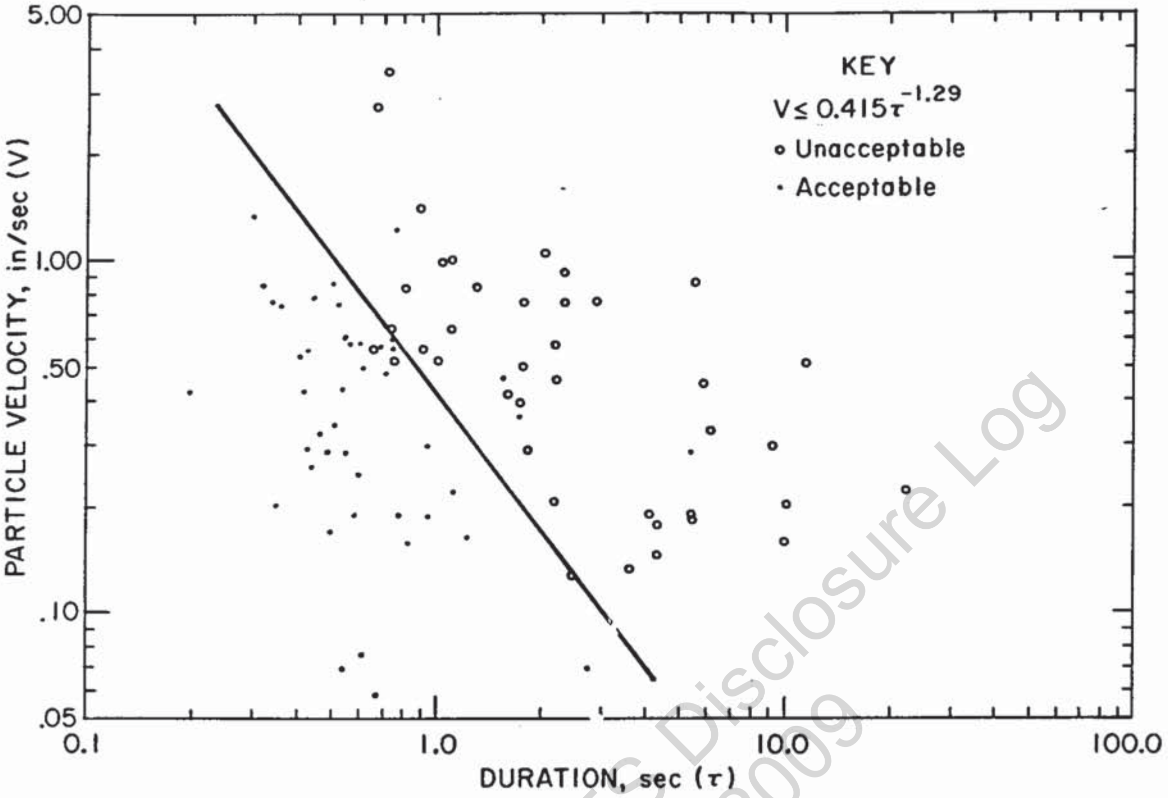

Figure 65.—Human response to concrete floor vibrations of various durations. Equation defines acceptable zone.

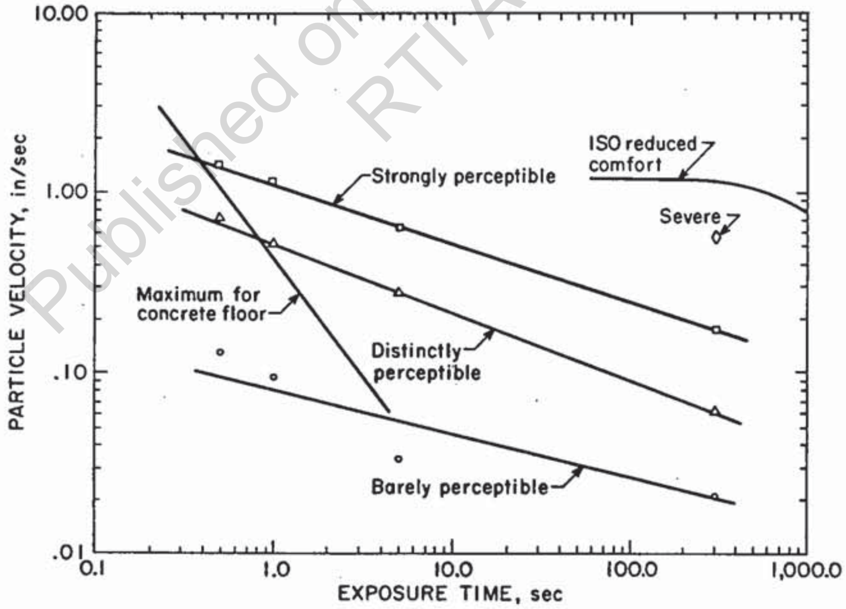

Figure 66.—Human response to vibrations of various durations, summary. ISO values are from Standard 2631.

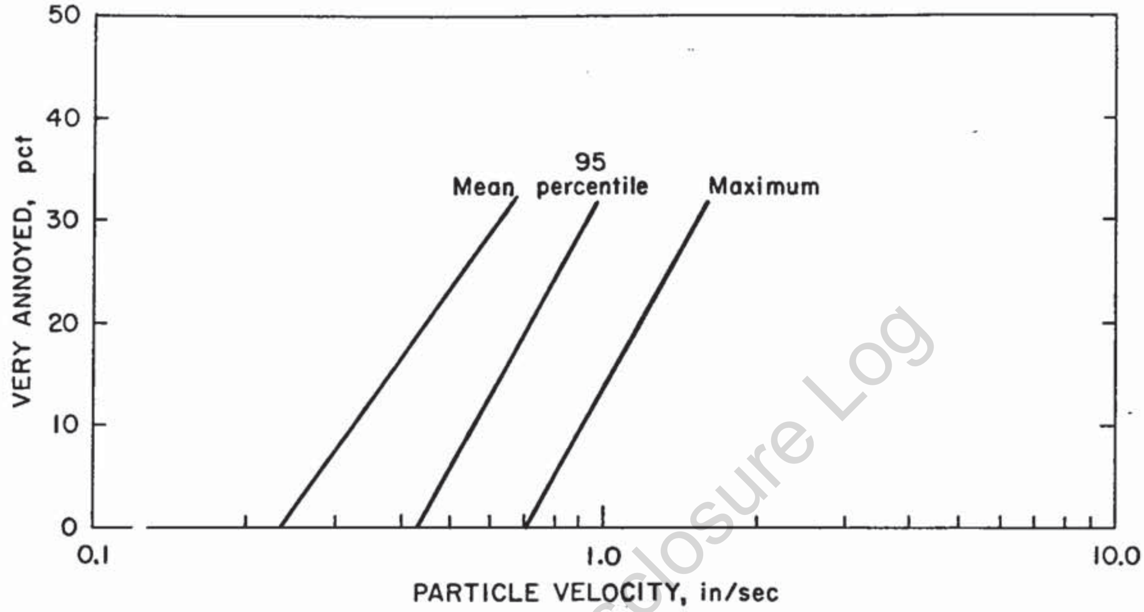

Figure 67.—Reactions of persons subjected to blasting vibration in their homes.

of the particle velocities. Since reactions are most likely from stronger events, actual public reaction would occur somewhere between that corresponding to the mean vibration level and the maximum, probably close to the 95th percentile. Exact determination of the airblast-produced human reactions (and also those produced by ground vibration) is not possible without knowing how closely the reported subjective reactions correspond to various levels of sonic boom experienced during the three test periods. It is possible and even likely that those interviewed reacted more to the higher level booms (e.g., maximum values). More work is needed to quantify reactions and specific levels. The potential for ground vibrations to produce strong public reaction is evident from figure 67. In the absence of a public relations program, it is expected that a mean ground vibration level of 0.50 in/sec in a community will produce 15 to 30 pct "very annoyed" neighbors. The 95-pct line gives 5 pct very annoyed at 0.5 in/sec. The blaster must convince the nearby homeowners that the rattling is to be expected and is not damaging. He can also demonstrate his sincerity by blasting as unobtrusively as possible, and using the best blast design principles.

Table 15.—Subjective responses of humans to vibrations of various durations

Type of response	Duration, sec	Particle velocity, in/sec	Source
Barely perceptible:			
Mean	0.5	0.130	Wiss and Parmelee (*58*).
Do	1	.095	Do.
Do	5	.033	Do.
Do	300	.020	Reiher and Meister (*40*).
Threshold	5	.011	Wiss and Parmelee (*58*).
Do	300	.011	Reiher and Meister (*40*).
Disticly perceptible:			
Mean	.5	.700	Wiss and Parmelee (*58*).
Do	1	.500	Do.
Do	5	.280	Do.
Do	300	.060	Reiher and Meister (*40*).
Threshold	.5	.300	Wiss and Parmelee (*58*).
Do	1	.230	Do.
Do	5	.100	Do.
Do	300	.033	Reiher and Meister (*40*).
Strongly perceptible:			
Mean	.5	1.400	Wiss and Parmelee (*58*).
Do	1	1.150	Do.
Do	5	.630	Do.
Do	300	.170[1]	Reiher and Meister (*40*).
Threshold	.5	.910	Wiss and Parmelee (*58*).
Do	1	.810	Do.
Do	5	.390	Do.
Do	300	.102	Reiher and Meister (*40*).
Severe:			
Mean	300	.550[1]	Do.
Threshold	5	1.13	Wiss and Parmelee (*58*).
Do	300	.301	Reiher and Meister (*40*).
Acceptable	0.2–4	$\leqq 0.415^{\tau 1.29}$	Murray (*33*).[2]

[1] At 9 Hz.
[2] τ = duration (sec).

CONCLUSIONS

The problems of blasting vibration damage to residential structures and human tolerance to vibrations have been analyzed using data from a wide variety of studies. Statistical techniques of mean and variance analysis and probability plots have both been applied to the damage data from the 10 studies and demonstrated the following:

1. Particle velocity is still the best single ground motion descriptor.
2. Particle velocity is the most practical descriptor for regulating the damage potential for a class of structures with well-defined response characteristics (e.g., single-family residences).
3. Where the operator wants to be relieved of the responsibility of instrumenting all shots, he could design for a conservative square root scale distance of 70 ft/lb$^{1/2}$. The typical vibration levels at this scaled distance would be 0.08 to 0.15 in/sec.
4. Damage potentials for low-frequency blasts (< 40 Hz) are considerably higher than those for high-frequency blasts (> 40 Hz), with the latter often produced by close-in construction and excavation blasts.
5. Home construction is also a factor in the minimum expected damage levels. Gypsumboard (Drywall) interior walls are more damage resistant than older, plaster on wood lath construction.
6. Practical safe criteria for blasts that generate low-frequency ground vibrations are 0.75 in/sec for modern gypsumboard houses and 0.50 in/sec for plaster on lath interiors. For frequencies above 40 Hz, a safe particle velocity maximum of 2.0 in/sec is recommended for all houses.
7. All homes eventually crack because of a variety of environmental stresses, including humidity and temperature changes, settlement from consolidation and variations in ground moisture, wind, and even water absorption from tree roots. Consequently, there may be no absolute minimum vibration damage threshold when the vibration (from any cause, for instance slamming a door) could in some case precipitate a crack about to occur.
8. The chance of damage from a blast generating peak particle velocities below 0.5 in/sec is not only small (5 pct for worst cases) but decreases more rapidly than the mean prediction for the entire range of vibration levels (almost asymptotically below about 0.5 in/sec).
9. Human reactions to blasting can be the limiting factor. Vibration levels can be felt that are considerably lower than those required to produce damage. Human reaction to vibration is dependent on event duration as well as level. Particle velocities of 0.5 in/sec from typical blasting (1-sec vibration) should be tolerable to about 95 pct of the people perceiving it as "distinctly perceptible". Relevant to whole-body vibration reaction is the degree that the vibration interferes with activity (sleep, speech, TV viewing, reading), presents a health hazard, and affects task proficiency. For people at home, the most serious blast vibration problems are house rattling, fright (fear of damage or injury), being startled, and for a few, activity interference. Complaints from these causes can be as high as 30 pct at 0.5 in/sec, and this is where good public relations attitudes and an educational program by the blaster are essential.

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APPENDIX A.—EXISTING VIBRATION STANDARDS AND CRITERIA TO PREVENT DAMAGE

The German vibration standards (DIN 4150) are intended to protect buildings but are so strict as to be unworkable (table A–1). Reportedly, they are not enforced, at least for blasting. No technical data have been given to justify the levels specified (*4, 52*).[1]

The Australian standard (CA 23–1967) specifies maximums of

(1) 0.008-in displacement for frequencies less than 15 Hz and

(2) 0.75 in/sec resultant peak particle velocity for frequencies greater than 15 Hz.

The 0.008-in maximum displacement corresponds to 0.5 in/sec at 10 Hz and 0.25 in/sec at 5 Hz.

Table A–1.—German vibration standards, DIN 4150

Type of construction	Peak pseudo vector sum particle velocity mm/sec	in/sec
Ruins, ancient and historic buildings given antiquities protection	2	0.08
Buildings with visible damage and cracks in masonry	4	.16
Buildings in good condition, possibly with cracks in plaster	8	.32
Industrial and concrete structures without plaster	10–40	.39–1.56

Skipp (*47*) lists a variety of national vibration limits, including the Czechoslovakian maximum code of 10 mm/sec (0.40 in/sec). Skipp states, "in countries without formal codes, good practice usually takes into account the intrusive element without specifying a particular damage state. In the U. K. for example for tunnel blasting, 10 mm/sec has been the aim in densely populated areas and 25 mm/sec in sparsely populated areas." The British Secretary of State specified that 12 mm/sec (0.47 in/sec) be used for surface coal mine blasts that generate frequencies below 12 Hz.

Bogdanoff's damage paper (*6*) summarizes safe values from the text "Rock Blasting," by Langefors and Kihlstrom (*25*), given in table A–2. The propagation velocity (c) is related to particle velocity (V) and ground strain (e) according to:

$$e = \frac{V}{c}$$

Table A–2.—Damage levels from blasting, after Langefors and Kihlstrom (*25*)

Damage effects	Peak particle velocity					
	Sand, gravel, clay below water level; c = 1,000 – 1,500 m/sec[1]		Moraine, slate, or soft limestone; c = 2,000 – 3,000 m/sec		Granite, hard limestone, or diabase; c = 4,500 – 6,000 m/sec	
	mm/sec	in/sec	mm/sec	in/sec	mm/sec	in/sec
No noticeable crack formation	18	0.71	35	1.4	70	2.8
Fine cracks and falling plaster threshold	30	1.2	55	2.2	100	~~3.9~~ 4,3
Crack formation	40	1.6	80	3.2	~~150~~ 160	~~5.9~~ 6,3
Severe cracks	60	2.4	115	4.5	~~225~~ 230	~~8.9~~ 9,1

[1] Propagation velocity in media is given by c.

Table A–3.—Limiting safe vibration values of pseudo vector sum peak particle velocities, after Esteves (*17*)

Type of construction	Peak particle velocity					
	Incoherent loose soils, soft coherent soils, rubble mixtures: c < 1,000 m/sec[1] c < 3,300 ft/sec[1]		Very hard to medium consistence coherent soils, uniform or well-graded sand: c = 1,000–2,000 m/sec c = 3,300–6,600 ft/sec		Coherent hard soils and rock: c > 2,000 m/sec c > 6,600 ft/sec	
	mm/sec	in/sec	mm/sec	in/sec	mm/sec	in/sec
Special care, historical monuments, hospitals, and very tall buildings	2.5	0.10	5	0.20	10	0.40
Current construction	5	.20	10	.40	20	.80
Reinforced construction, e.g., earthquake resistant	15	.60	30	1.20	60	2.40

[1] Propagation velocity in media given by c.

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[1] Italic numbers in parentheses refer to items in the list of references preceding the appendixes.

Consequently, low-velocity materials will have higher ground strains (and potentials for failure) for a given particle velocity. Langefors and Kihlstrom did not give the experimental data to support their thresholds of table A–2. Esteves' study (*17*) includes safe values for a variety of conditions, including types of soil, construction, and frequency of blasting (table A–3). As with Langefors and Kihlstrom (table A–2), Esteves does not give the supporting experimental data. Ashley lists maximum particle velocities for a variety of structure types (*1*). Again, technical data to derive or support the recommended values are not given (table A–4).

Several survey papers have been written that combined nuclear blast, earthquake, and blasting data without pointing to the variations among vibration characteristics and the resulting response and damage potentials (*20, 34*). The worst-case experimental data are from the Salmon nuclear blast and the Mercury, Nev., studies. These results are overly conservative for blasting, and their use cannot be justified on technical grounds.

Cases occasionally arise where blasting vibration is considered a potential problem to equipment, or concern is expressed about the vibration sources such as traffic. The safe level criteria established for blasting are often applied to these situations with little justification. Traffic is usually a steady-state source of low amplitude. Appropriate safe levels would have to be lower than for blasting, which is relatively infrequent and of shorter duration. The British criterion for architectural damage from steady-state sources is 5 mm/sec (0.20 in/sec) (*55*). Vibration standards for laboratory instruments are given in table A–5.

Table A–4.—Limiting safe vibration values, after Ashley (*1*)

Type of construction	Peak particle velocity	
	mm/sec	in/sec
Ancient and historic monuments	7.5	0.30
Housing in poor repair	12	.47
Good residential, commercial, and industrial structures	25	1.0
Welded gas mains, sound sewers, engineered structures	50	2.0

Table A–5.—Vibration limits for laboratory instruments, after Whiffin and Leonard (*55*)

Dimensional and electrical physical reference standards	g[1]	0.01
Do	in/sec	[2]0.031
Dimensional working standards	g	0.02
Do	in/sec	[2]0.062
Electrical, physical working standards	g	0.03
Do	in/sec	[2]0.093
General electronic apparatus	in/sec	0.19
Mettler analytical balance	in/sec	[2]0.0125
Sartorius analytical balance	in/sec	[2]0.10
Leeds—Northrup Reflection Galvanometer	in/sec	[2]0.0125
Photo microscope	in/sec	1.44
Phillips EM 300 electron microscope	in/sec	0.00015
HAAS standards barometer	in/sec	0.08

[1] g = acceleration of gravity 9.8 m/sec^2 (32.2 ft/sec^2).
[2] At 20 Hz.

APPENDIX B.—ALTERNATIVE BLASTING LEVEL CRITERIA

Safe blasting vibration criteria were developed for residential structures, having two frequency ranges and a sharp discontinuity at 40 Hz (table 13). There are blasts that represent an intermediate frequency case, being higher than the structure resonances (4 to 12 Hz) and lower than 40 Hz. The criteria of table 13 apply equally to a 35-Hz and a 10-Hz ground vibration, although the responses and damage potentials are very much different.

Using both the measured structure amplifications (fig. 39) and damage summaries (figs. 52 and 54), a smoother set of criteria was developed. These criteria have more severe measuring requirements, involving both displacement and velocity (fig. B–1).

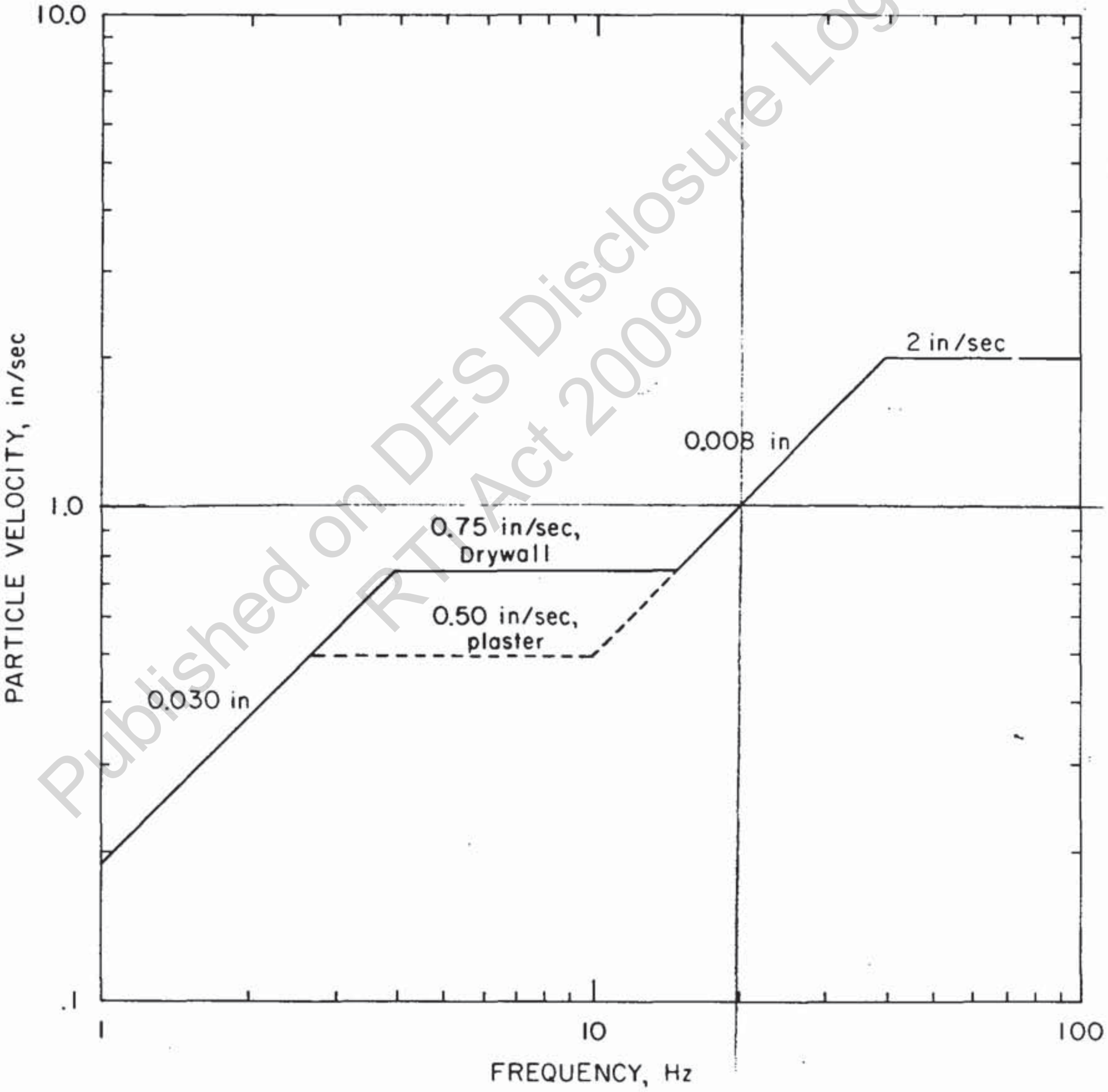

Figure B–1.—Safe levels of blasting vibration for houses using a combination of velocity and displacement.

Above 40 Hz, a constant peak particle velocity of 2.0 in/sec is the maximum safe value. Below 40 Hz, the maximum velocity decreases at a rate equivalent to a constant peak displacement of 0.008 in. At frequencies corresponding to 0.75 in/sec for Drywall, and 0.50 in/sec for plaster, constant particle velocities are again appropriate. An ultimate maximum displacement of 0.030 in is recommended, which would only be of concern where very low frequencies are encountered (< 4 Hz).

This scheme is based on the response and damage data, recognizes the displacement-bound requirement for house responses to blast vibrations, and provides a smooth transition for the intermediate frequency cases. This method of analyzing the damage potential of blasting vibrations has the disadvantage of possibly underestimating annoyance reactions. Midwall responses (fig. 40) do not decrease nearly as fast as structure (corner) responses as frequencies increase from 10 to 40 Hz. A very nearly linear decrease of velocity amplification was observed for the gross structure; however, the higher midwall response frequencies will make the 20- to 35-Hz vibrations relatively annoying if the maximum levels shown on figure B–1 are attained.

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STRUCTURE RESPONSE AND DAMAGE PRODUCED BY GROUND VIBRATION FROM SURFACE MINE BLASTING

by

David E. Siskind, Mark S. Stagg,
John W. Kopp, and Charles H. Dowding

ERRATA

Page 1, line 14 should read "Safe levels" instead of "Save levels."

Page 3, footnote should read "Italic numbers" instead of "Underlined numbers."

Page 12 (table 1): Seven shots that were omitted are given on the attached page. In addition, for shot 134 "Peak ground vibration (H_2)" should be 0.32 instead of 0.36, and the column heading labeled "Sealed distance" should read "Scaled distance."

Page 19 (equation 2): Sign before $\frac{\beta}{\sqrt{1-\beta^2}}$ should be minus instead of plus.

Page 23 (table 3): Structures numbered 58 and above have some of the shots improperly indicated. The attached table shows the correct values, and is consistent with table 1.

Page 28, caption of figure 28 should be "Test structure 61, near a construction site."

Page 41 (table 5): Footnote 4 should show 119 dB airblast instead of 111 dB.

Page 42 (table 6): Values in "Mine blasts" column should read 0.377 instead of 0.472 and .314 instead of .392. Footnote 1 should have 119 dB airblast instead of 111 dB.

Page 48 (table 9): Jensen and Rietman reference number should be 21 instead of 57. Also, under "Damage observed, uniform classification," Nondamage and Threshold values for "Bureau of Mines new data" should be 76 and 28, respectively, not 37 and 23.

Page 71 (table A-2): Values in the "Granite, hard limestone, or diabase" column should be as follows:

mm/sec	in/sec
70	2.8
110	4.3
160	6.3
230	9.1

ADDITIONAL VALUES FOR TABLE 1 OF RI 8507

Production blasts and ground vibration measurements

Shot	Facility	Shot type	Total charge lb.	Lb per delay	Scaled distance $ft/lb^{1/2}$	Peak ground vibration, in/sec			Peak structure motion, in/sec							Structure number (table 3)	Struc-ture type
									Low corner			High corner		Midwall			
						H_1	H_2	V	H_1	H_2	V	H_1	H_2	H_1	H_2		
155	Coal	Highwall..	5,400	120	43.0		0.43	0.55						0.84		44	1
156	Coal	....do....	3,600	80	41.0		0.96	0.57						0.76		44	1
173	Coal	....do....	2,150	86	27.0	0.59	0.96	1.01	0.56	0.66	1.19			0.74	2.55	51	2
176	Coal	....do....	3,550	71	6.9	5.58	2.34	2.61	2.85	1.32	4.09	3.43	1.41	9.14	2.69	51	2
177	Coal	....do....	3,240	36	9.7	3.90	2.44	1.65	2.13	2.2	2.60	3.53	2.28	7.06	2.82	51	2
209	Coal	....do....		80	19.0	4.50	1.17	1.[illegible]								58	1
W-17	Constr	Excavation	50	13	1.4	5.83	11.87	6.49	8.05	[illegible]	9.62	2.77	2.03	5.8	8.69	67	2

CORRECTIONS FOR TABLE 3 OF RI 8507

Test structures and measured dynamic properties

Structure	Shots (table 1)
57	201,202
58	203-209
59	W-1
60	W-2, W-3
61	W-4, W-5
62	W-6
63	W-7, W-8
64	W-9, W-10
65	W-11, W-12
66	W-13, W-14, W-15
67	W-16, W-17
68	W-18, W-19
69	W-20, W-21
70	W-22
71	W-23
72	W-24
73	W-25, W-26, W-27
74	W-28, W-29
75	W-30
76	W-31, W-32