U.S. DEPARTMENT OF THE INTERIOR

OFFICE OF SURFACE MINING

RECLAMATION AND ENFORCEMENT

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Approval: Jed D. Christensen Title: Director

1. PURPOSE. This directive is to inform all OSMRE employees of the availability of the OSMRE Blasting Guidance Manual. This manual was developed to give guidance to regulatory authorities, the public and industry on the use of explosives and the examination and certification of blasters.

2. DEFINITIONS. None

3. POLICY/PROCEDURES.

   The OSMRE Blasting Guidance Manual was developed to give guidance to regulatory authorities, the public and industry on the use of explosives and the examination and certification of blasters. This document also satisfies a commitment the agency made in the preamble to the Use of Explosives regulations (48 FR 9801, March 8, 1983) that a technical guidance document would be made available demonstrating the application of the modified scaled distance equation and determination of predominant frequency in the use of the alternate blasting criteria found in 30 CFR 816/817.67(d)(4). The manual can also be used to partially meet the blaster training requirements of 30 CFR 850.13.

4. REPORTING REQUIREMENTS. None

5. REFERENCES. See attached appendix

6. EFFECT ON OTHER DOCUMENTS. None

7. EFFECTIVE DATE. Upon issuance

8. CONTACT.

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BLASTING GUIDANCE MANUAL

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March 1987

Office of Surface Mining Reclamation and Enforcement
UNITED STATES DEPARTMENT OF THE INTERIOR

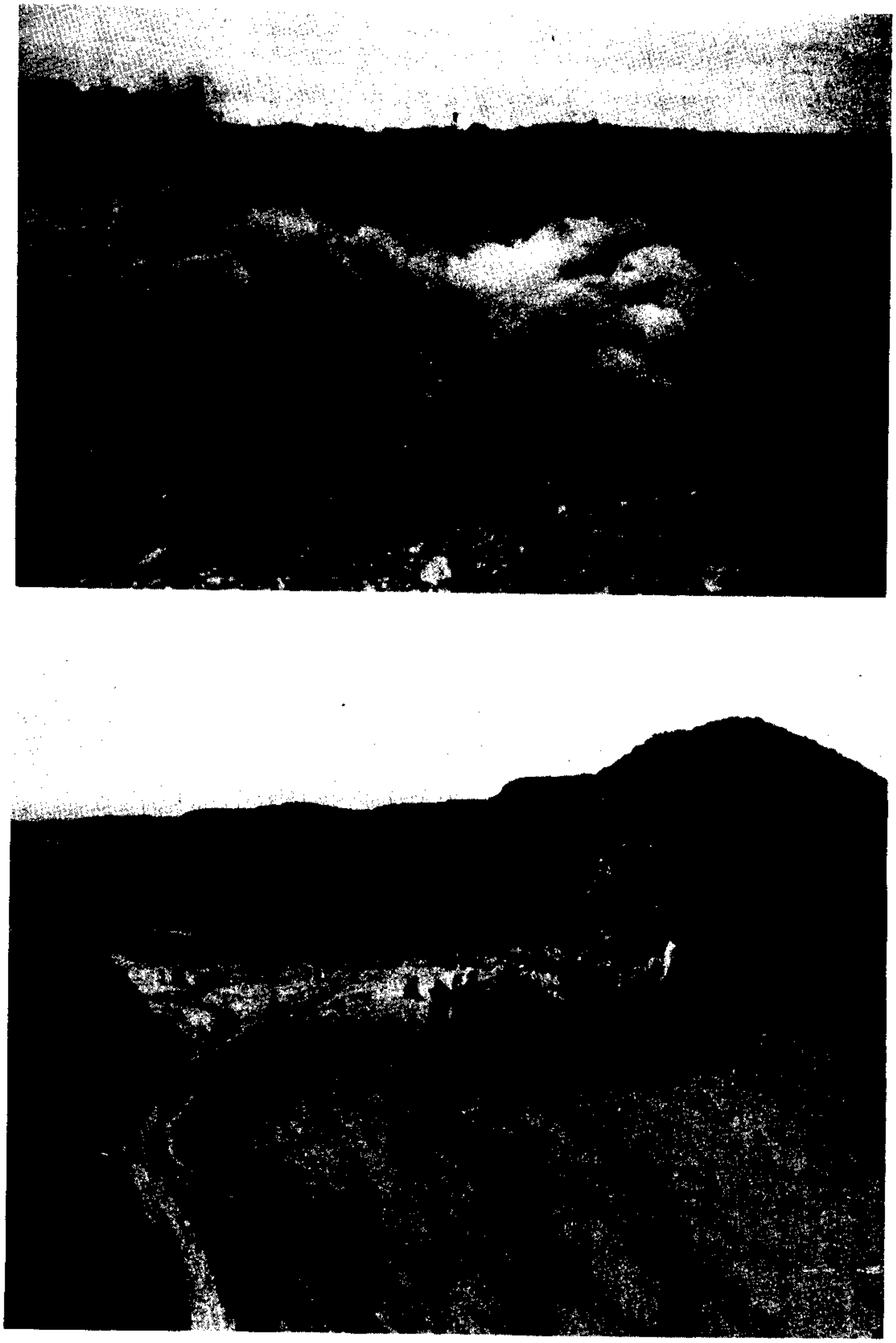


Figure 1.
Surface Mine Blasts.

TABLE OF CONTENTS

PAGE

CHAPTER 1

CHAPTER 2

CHAPTER 3

CHAPTER 4

CHAPTER 5

CHAPTER 6

CHAPTER 7

CHAPTER 8

PAGE

CHAPTER 9

CHAPTER 10

CHAPTER 11

CHAPTER 12

CHAPTER 13

APPENDIX 'A'

APPENDIX 'A' (Continued)

APPENDIX 'B'

APPENDIX 'C'

APPENDIX 'D'

ILLUSTRATIONS AND FIGURES

Illustrations & Figures - Contd.

TABLES

BLASTING GUIDANCE MANUAL

INTRODUCTION

The Office of Surface Mining Reclamation and Enforcement (OSMRE) Permanent Regulatory Program Sections 816.61-68 and 817.61-68, as published in the Federal Register on March 8, 1983, will be referred to henceforth simply as the OSMRE regulations. They were designed to protect the general public against the possible negative effects of surface mining as a whole. Throughout this document reference will always be made to Section 816 alone for the sake of clarity, since the detailed paragraphs in both Sections are identical. Whenever such reference to Section 816 is made, it is to be understood that equal reference is made to Section 817.

This Guidance Manual deals particularly with the negative effects of blasting, and applies to all blasting, regardless of the total weight of explosives detonated. The only variance allowed, under Section 816.61(b), is that blasts under 5 lbs. in total weight do not have to comply with the Blasting Schedules otherwise required under Section 816.64.

The intent of Congress in the Act [Public Law 95-87,(Act), Section 515(b)(15)(c)] was to prevent (i) injury to persons, (ii) damage to public and private property outside the permit area, (iii) adverse impacts on any underground mine, and (iv) change in the course, channel, or availability of ground or surface water outside the permit area. No regulation can circumvent the will of Congress. This therefore means that the OSMRE regulations apply to all surface coal mine operators, whenever they blast.

However, this Manual is also intended to make compliance with the OSMRE regulations as easy, practical and as beneficial to the operator as possible, while still affording the environmental and safety standards required by the Act. It will show that compliance is not only a matter of observing perhaps onerous restrictions, but also that there are definite advantages that can accrue from such compliance. These advantages, if fully exploited, will in part - or even entirely - offset the cost of compliance. They could improve the efficiency of blasting operations, lower explosive costs, cut drilling costs, and generally improve profitability. They will certainly improve safety.

This Manual will also address the several different ways in which compliance may be effected, always at the option of the mine operator. It will attempt to explain the relative merits of each method, in practical everyday terms.

Introduction

In addition to this, the Manual is offered as self-training for the control and prediction of blasting effects, and as a partial basis for self-study for OSMRE blaster certification. It is presented as a source of up-to-date information on damage criteria and state of the art methodology for those who find themselves in the position of having to formulate blast vibration ordinances. Last, but not least, the Manual is intended to provide a basic reference and field guide for OSMRE inspection and enforcement personnel.

A study of the adverse effects of blasting will be covered in detail: ground vibration, airblast and flyrock, and the methods by which these effects can be monitored and controlled will be described. Pre- and Post-Blast Surveys, Instrumentation, Record Keeping and some of the subjective human issues that greatly influence our activities will be discussed. If these principles and lessons are applied to all everyday activities in surface coal mining, it will not only be found that the OSMRE regulations are complied with, but it will also:

- Improve public good will
- Enhance the public image of a surface coal mining operation
- Reduce complaints
- Avoid most lawsuits
- Win unavoidable lawsuits
- Improve blasting efficiency
- Reduce costs
- Increase profitability
- Improve safety
- Mitigate the adverse effects of blasting

CHAPTER 1

PRE-BLAST SURVEYS

REQUIREMENT BY LAW: Unlike many other sections of the OSMRE regulations, the requirement to carry out pre-blast inspections of properties within one half mile of the permit is specified in the original Public Law 95-87, August 3, 1977, (Section 515(b)(15)(E)). The Act states the "The Regulatory Authority .... shall include provisions to provide that upon the request of the resident or owner of a man-made dwelling or structure within one-half mile of any portion of the permitted area the applicant or permittee shall conduct a pre-blast survey of such structures and submit the survey to the regulatory authority and a copy to the resident or owner making the request".

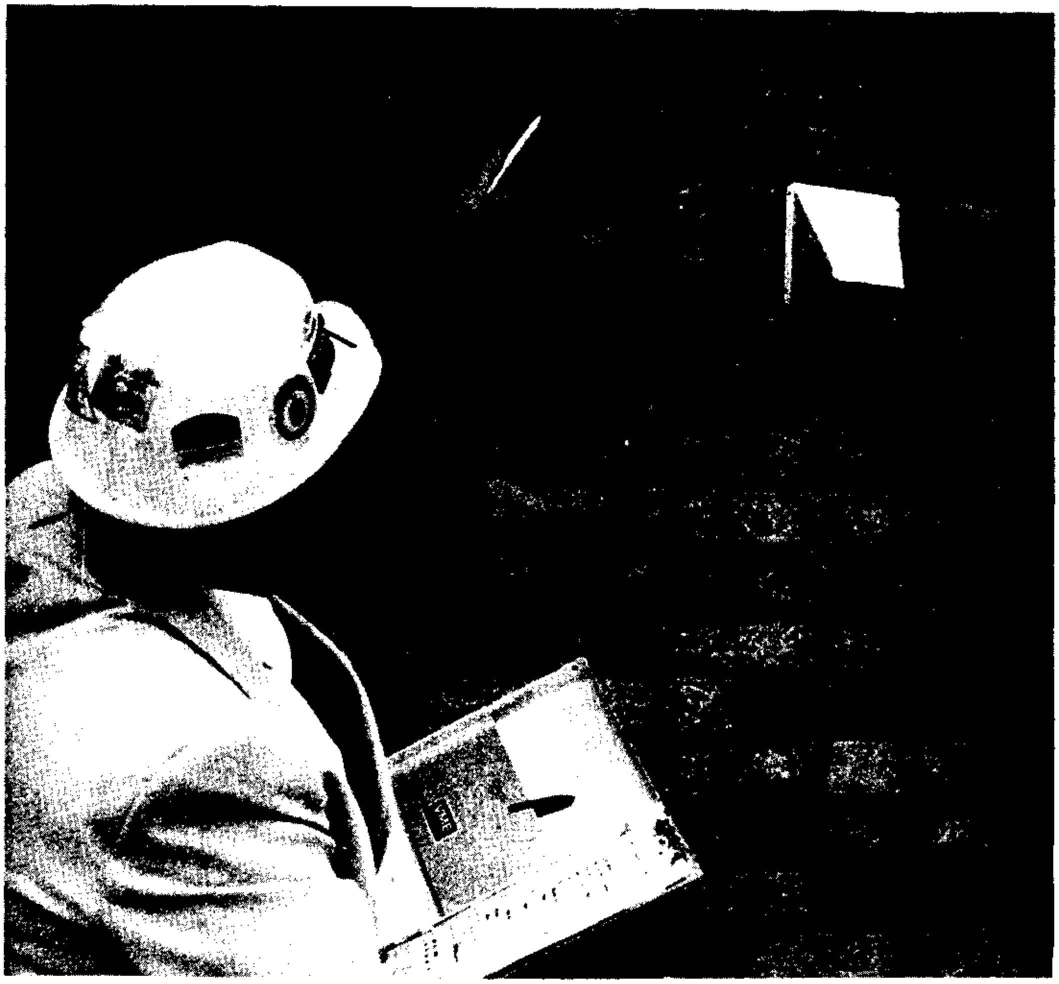


Figure 2.
Pre-blast Survey: Documenting defects.

Pre-Blast Surveys

OSMRE REGULATIONS: The specific requirements of the pre-blasting survey are included in Section 816.62 of the OSMRE regulations. The operator is required to carry out an inspection of any dwelling or structure within one-half mile of the permit area if requested in writing by the owner or resident. The owner or resident must be contacted by letter at least 30 days before the start of blasting, notifying them how they may request a pre-blasting survey. The final written inspection report must be signed by the person making the survey and copies are to be provided both to the regulatory authority and the person requesting the survey. Since the operator will want to keep a record of each survey, as also will the independent consultant carrying out the survey, if employed, this means that at least 4 copies will be required.

The survey report must determine the condition of the dwelling or structure and must document any pre-existing defects and other physical factors that could reasonably be affected by the blasting. Structures such as pipelines, cables and transmission lines, also cisterns, wells and other water systems warrant special attention; however the assessment of these structures may be limited to visible surface conditions and other readily available information.

The main intent of the pre-blasting survey is to provide independent documentation of the existing physical condition of the structure with the location and the dimensions of each observable defect clearly noted.

CAUSES OF STRUCTURAL DEFECTS: Minor defects in structures such as cracks in plaster, masonry and other structural materials are extremely common and are usually the result of the relative movement of the different materials of construction with changes in temperature and humidity. Other more serious defects can result from other causes and the United States Department of the Interior, Bureau of Mines, has published in Bulletin 442, "Seismic Effects of Quarry Blasting", a list of forty causes of cracks appearing in walls and ceilings.

None of the following causes are related to the application of explosives; however, the homeowner often becomes so sensitized by the perceived effects of blasting that he believes that many long standing defects in his dwelling are the result of blasting. These 40 causes are listed as follows:

1. Building a house on fill.
2. Failure to make the footings wide enough.
3. Failure to carry the footings below the frost line.

4. Width of footings not made proportional to the load they carry.
5. The posts in the basement not provided with separate footings.
6. Failure to provide a base raised above the basement floor line for the setting of wooden posts.
7. Not enough cement used in the concrete.
8. Dirty sand or gravel used in the concrete.
9. Failure to protect beams and sills from rotting.
10. Setting the floor joists one end on masonry and the other on wood.
11. Wooden beams used to support masonry over openings.
12. Mortar, plaster or concrete work allowed to freeze before setting.
13. Braces omitted in wooden walls.
14. Sheathing omitted in wooden walls (except in "Back-Plastered" construction).
15. Drainage water from roof not carried away from the foundations.
16. Floor joists too light.
17. Floor joists not bridged.
18. Supporting posts too small.
19. Cross beams too light.
20. Subflooring omitted.
21. Wooden wall not framed so as to equalize shrinkage.
22. Poor material used in plaster.
23. Plaster applied too thin.
24. Lath placed too close together.
25. Lath run behind studs at corners.
26. Metal reinforcement omitted in plaster at corners.

27. Metal reinforcement omitted where wooden walls join masonry.

28. Metal lath omitted on wide expanses of ceiling.

29. Plaster applied directly to masonry at chimney stack.

30. Plaster applied on lath that are too dry.

31. Too much cement in stucco.

32. Stucco not kept wet until set.

33. Subsoil drainage not carried away from walls.

34. First coat of plaster not properly keyed to backing.

35. Wooden beams spanned too long between posts.

36. Failure to use double joists under unsupported partitions.

37. Floor joists placed too far apart.

38. Too few nails used.

39. Rafters too light or too far apart.

40. Failure to erect trusses over wide wood openings.

CHANGES IN CONDITION WITH TIME: Any or all of these listed causes may result in cracks or defects. As time passes, dimensional changes due to seasonal temperature and humidity fluctuations can be expected to render those defects more visible, or to widen or lengthen cracks. The causes of the defects, if uncorrected, will continue to have an effect even after the pre-blast survey has been completed. It is, therefore, very important that any structural defects or conditions which could be expected to worsen with time should be clearly identified. The homeowner or resident of any property should be made aware that such changes can occur, and why they occur, or they may be incorrectly attributed to the blasting vibration effects. In some cases the presence of serious structural problems may necessitate that lower vibration levels be imposed on a particular structure to prevent further deterioration. These structural defects or problems must be documented in any report.

INSPECTION PROCEDURES: The OSMRE regulations do not specify who should carry out the pre-blast inspection. In most cases they will be carried out by an independent consultant specializing in the field of blasting vibrations and their effects on structures. The use of an independent consultant will avoid any problem of 'conflict of interest' that might arise should the operator's own personnel be used. If practical, the homeowner or resident should accompany the inspector during the inspection so that they are made aware of the procedures, and the defects noted.

If accompanied by the homeowner or resident, maximum benefit may be derived from the required survey if the inspector uses the opportunity to establish a positive public relations image. Not only should the procedures be described, but if possibilities exist that the blast vibrations will be, or have been, perceptible at the dwelling, these subjective effects should be frankly discussed and the perceived effects explained.

In conducting a pre-blasting survey of a building it is essential to document the location, length and width of any crack or other defect which may be visible on both the interior and exterior surfaces of the building.

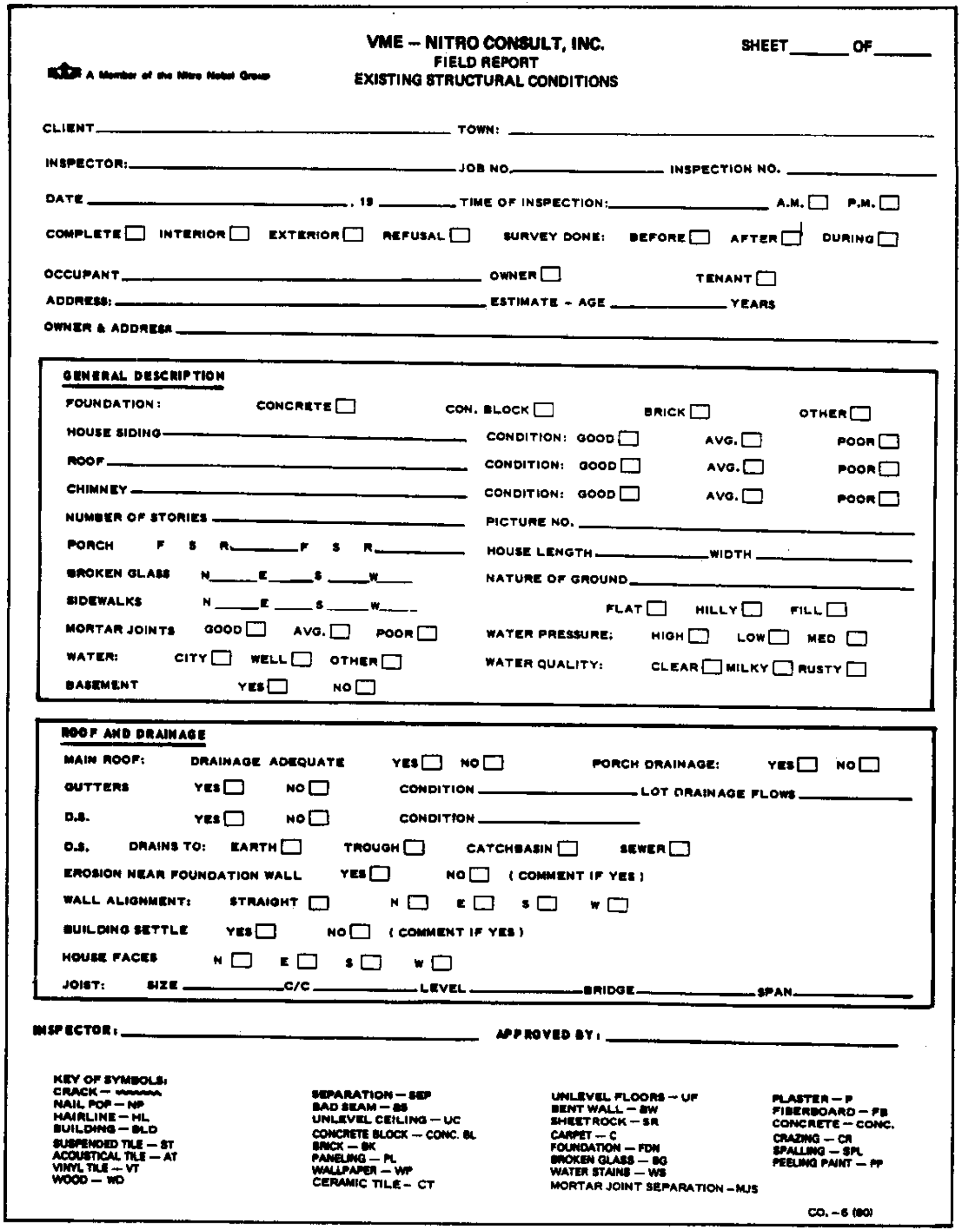
Figure 3.
Tape recording defects.

Various techniques are used to carry out pre-blasting surveys including recording the defects on video tape, audio cassette tape or by hand written notes either in narrative form or on a pre-prepared form. In nearly every case photographs are also used to document the major defects present, or to support the descriptive text.

In recent years video tape recording has become more popular but in most cases the lack of resolution in all but the most expensive equipment and the need to use additional lighting has limited its use for internal inspections. The OSMRE and Public Law 95-87 requirement that a written report of the pre-blast inspection be provided rules out the use of video tape except as a supplementary form of documentation. As video tape equipment improves and becomes more portable it might be that inspections using this method may become more acceptable. In addition to this consideration, however, in order to satisfy the Law on copies, it would be necessary to provide copies of the video tapes to all recipients. This might prove to be an unacceptable additional cost.

The most popular and accepted methods presently used by consulting firms and industry to carry out pre-blast inspections are tape recorded notes in narrative form, later transcribed in a typed report, augmented by photographs of each of the significant defects. They can also use prepared forms or wall/ceiling diagrams supported by hand written notes and photographs.

Examples of these inspection types and of typical pre-prepared forms are shown in Figures 2, 3, 4 and 5.



A Member of the Nitro Nobel Group

VME – NITRO CONSULT, INC.
FIELD REPORT
EXISTING STRUCTURAL CONDITIONS

SHEET ______ OF ______

CLIENT ____________ TOWN: ____________

INSPECTOR: ____________ JOB NO. ____________ INSPECTION NO. ____________

DATE ____________, 19 ______ TIME OF INSPECTION: ____________ A.M. ☐ P.M. ☐

COMPLETE ☐ INTERIOR ☐ EXTERIOR ☐ REFUSAL ☐ SURVEY DONE: BEFORE ☐ AFTER ☐ DURING ☐

OCCUPANT ____________ OWNER ☐ TENANT ☐

ADDRESS: ____________ ESTIMATE - AGE ______ YEARS

OWNER & ADDRESS ____________

GENERAL DESCRIPTION

FOUNDATION: CONCRETE ☐ CON. BLOCK ☐ BRICK ☐ OTHER ☐

HOUSE SIDING ____________ CONDITION: GOOD ☐ AVG. ☐ POOR ☐

ROOF ____________ CONDITION: GOOD ☐ AVG. ☐ POOR ☐

CHIMNEY ____________ CONDITION: GOOD ☐ AVG. ☐ POOR ☐

NUMBER OF STORIES ____________ PICTURE NO. ____________

PORCH F S R______ F S R______ HOUSE LENGTH ______ WIDTH ______

BROKEN GLASS N____ E____ S____ W____ NATURE OF GROUND ____________

SIDEWALKS N____ E____ S____ W____ FLAT ☐ HILLY ☐ FILL ☐

MORTAR JOINTS GOOD ☐ AVG. ☐ POOR ☐ WATER PRESSURE: HIGH ☐ LOW ☐ MED ☐

WATER: CITY ☐ WELL ☐ OTHER ☐ WATER QUALITY: CLEAR ☐ MILKY ☐ RUSTY ☐

BASEMENT YES ☐ NO ☐

ROOF AND DRAINAGE

MAIN ROOF: DRAINAGE ADEQUATE YES ☐ NO ☐ PORCH DRAINAGE: YES ☐ NO ☐

GUTTERS YES ☐ NO ☐ CONDITION ____________ LOT DRAINAGE FLOWS ____________

D.S. YES ☐ NO ☐ CONDITION ____________

D.S. DRAINS TO: EARTH ☐ TROUGH ☐ CATCHBASIN ☐ SEWER ☐

EROSION NEAR FOUNDATION WALL YES ☐ NO ☐ (COMMENT IF YES)

WALL ALIGNMENT: STRAIGHT ☐ N ☐ E ☐ S ☐ W ☐

BUILDING SETTLE YES ☐ NO ☐ (COMMENT IF YES)

HOUSE FACES N ☐ E ☐ S ☐ W ☐

JOIST: SIZE ______ C/C ______ LEVEL ______ BRIDGE ______ SPAN ______

INSPECTOR: ____________ APPROVED BY: ____________

KEY OF SYMBOLS:
CRACK — 〰〰
NAIL POP — NP
HAIRLINE — HL
BUILDING — BLD
SUSPENDED TILE — ST
ACOUSTICAL TILE — AT
VINYL TILE — VT
WOOD — WD

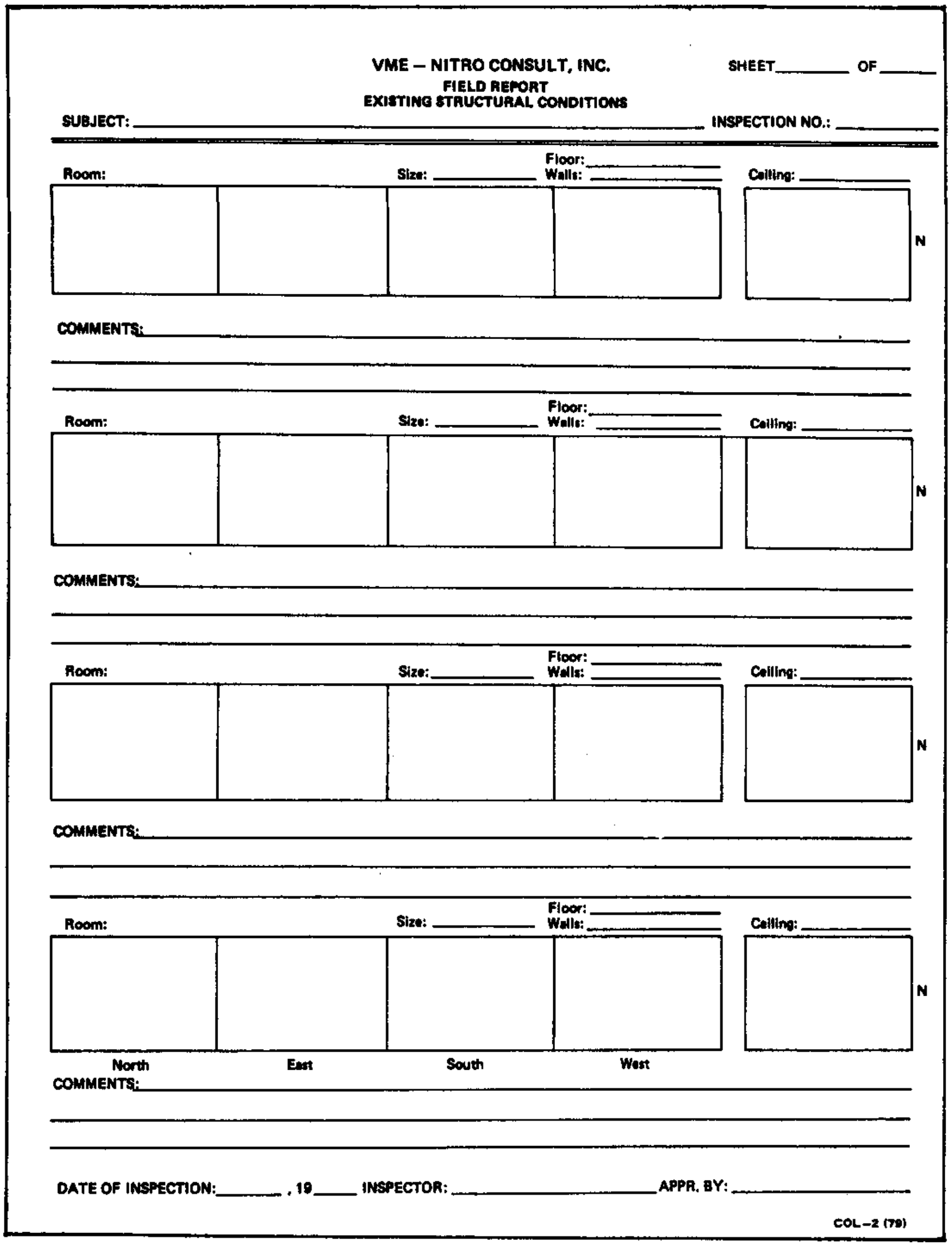
SEPARATION — SEP
BAD SEAM — BS
UNLEVEL CEILING — UC
CONCRETE BLOCK — CONC. BL
BRICK — BK
PANELING — PL
WALLPAPER — WP
CERAMIC TILE — CT

UNLEVEL FLOORS — UF
BENT WALL — BW
SHEETROCK — SR
CARPET — C
FOUNDATION — FDN
BROKEN GLASS — BG
WATER STAINS — WS
MORTAR JOINT SEPARATION — MJS

PLASTER — P
FIBERBOARD — FB
CONCRETE — CONC.
CRAZING — CR
SPALLING — SPL
PEELING PAINT — PP

CO. – 6 (80)

Figure 4.



VME — NITRO CONSULT, INC.
FIELD REPORT
EXISTING STRUCTURAL CONDITIONS

SHEET ______ OF ______

SUBJECT: ____________________ INSPECTION NO.: ______

Room: Size: ______ Floor: ______ Walls: ______ Ceiling: ______

N

COMMENTS: ____________________

Room: Size: ______ Floor: ______ Walls: ______ Ceiling: ______

N

COMMENTS: ____________________

Room: Size: ______ Floor: ______ Walls: ______ Ceiling: ______

N

COMMENTS: ____________________

Room: Size: ______ Floor: ______ Walls: ______ Ceiling: ______

N

North East South West

COMMENTS: ____________________

DATE OF INSPECTION: ______ , 19____ INSPECTOR: ______________ APPR. BY: ______________

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Figure 5.

An important function of the pre-blast survey is that of recording existing problems that might be expected to deteriorate independent of any blasting. Noting the fact that a building might be historically valuable or fragile is sometimes overlooked; as is noting the presence of unusually costly or vulnerable contents. The OSMRE regulations protect persons and property, and it may be forgotten that the property at risk might be a particularly vulnerable building, or even the contents of that building.

Section 850.13(b)(10)(iii) refers to training in the "use of pre-blast surveys in blast design". In all normal situations, of course, a pre-blast survey has no direct bearing on blast design. The survey records pre-existing defects, while the blast design, among other considerations, ensures that vibrations do not exceed regulatory limits.

However, should that structure be a historical building, for example, containing valuable collections on exhibit, then special considerations might have to apply. Vibrations that would present no threat of even cosmetic damage to a modern building, might cause damage to a very old structure, and could possibly cause fragile contents to fall and break. Under circumstances such as these, blast design can indeed be dependent on the pre-blast survey.

In terms of protecting contents, much will depend on individual circumstances. Apart from the nature of the valuables, the type of support or mounting is of significance. Inclined or shaky shelves or cabinets, or insecure wall mountings will present breakage risks quite apart from blasting vibrations. No great threat would normally be imposed by regulatorily compliant vibrations, provided mountings or supports were stable, level, and in good condition. It would obviously be unnecessary to impose special restrictions on blast design if it were only that a householder had a collection of porcelains in cabinets, for example. In a case like this, however, it would nevertheless be appropriate to warn the householder, and advise that such valuables be placed in safe places. Double-sided foam mounting tape can often provide a secure answer to this type of problem.

The final written report, together with any copies, must include any photographs of the visible defects. These photographs may be either black and white or color but must be of such a size that the photographed defects can be seen by the naked eye.

The inspections of cisterns, wells, etc., may be limited to "surface conditions" but all available data should be documented, including in many cases a chemical analysis of the water supply. Historically, many wells have been shown to vary in volume and water quality, and, in some cases, a separate hydrologic study may be of value. If blasting commences at a time when a seasonal flow reduction is usual, a separate water report will prove invaluable.

Post-blasting surveys are normally required only in the event that a homeowner or resident makes a specific blast-related damage claim. A post-blasting survey, then, will be based on the particular damage claim, and will serve simply to confirm or deny the validity of the damage claim. The complaint damage itself should be inspected, documented and photographed if necessary, and comparison reference should be made to the original pre-blasting survey report. Note should be taken of whether the original report listed the defect and whether the original report listed any structural or other conditions that might have led to the appearance of the defect independent of any blasting activity. For this reason, particularly if the conclusion of the post-blasting survey might be to deny the damage claim, it is preferable that it be conducted by an independent specialist consultant.

SUMMARY: A pre-blasting survey, to be of real value, has to be done with care ensuring that no observable defects are omitted. A poor inspection in which defects are omitted will be of little value to an operator. In many cases, homeowners are unaware of all the defects present in their homes, but the sensitivity of human beings to vibration effects from blasting can result in their inspecting their homes more closely than usual and perhaps noticing pre-existing defects for the first time. It should also be remembered that the homeowner will have a copy of the pre-blasting survey report.

If local public relations are not good, or if relations between the mine and the homeowners are strained, it could be that a homeowner will apply himself to discover a missed defect. He may have several weeks in which to conduct such a search, compared to the hour or so available to the original inspector. Such defects, unless recorded in the pre-blasting survey, could logically be expected to have been caused by the blasting. It is exactly for this reason that a good pre-blasting survey should not only contain the location and type of each existing defect but also some comment, where possible, on existing structural problems which could be expected to cause further new defects or the worsening of existing defects. Typically, houses are not engineered structures, and some deterioration can be expected from the day the structure is built, largely because of the wide variety of materials used in their construction. Each material undergoes differential expansion and contraction with changes in temperature and humidity and some materials such as plaster undergo internal chemical changes with age which can reduce their physical strength. Although such changes are to be expected, there is no doubt that a good pre-blast inspection provides good baseline data on which to judge the validity of a claim of alleged blasting damage, and serves to protect both the interests of the operator and the property owner.

CHAPTER 2

BLAST VIBRATIONS: BASIC PRINCIPLES AND PARAMETERS

When a blast is detonated, a great deal of energy is liberated. In a well designed blast, most of that energy will be spent in breaking rock, but some will be converted into vibrations, either ground motion or air overpressure ("air-blast"). In a badly designed blast, where poor breakage is obtained, or where the holes are over or under loaded, it can be that much of the liberated energy is converted into vibrations, since it is not expended in fragmenting the rock, as it should be.

Ground motion is the principal vibration that will result from blasting, though airblast may be more noticeable because of the accompanying noise effects. The ground motion is literally a wave motion spreading outwards from the blast, much as the ripples spread outwards from the impact of a stone dropped into a pool of water. The earth, or rock, through which this wave travels is considered to be an elastic medium, composed of innumerable individual particles. As a disturbance occurs, each of these particles are set into a random oscillatory motion about their rest positions, a wave being generated as each particle transmits energy successively to the next. Energy losses occur with each successive transmission, so that as the vibration wave spreads outward, it diminishes in intensity, and the particles gradually return to their rest positions.

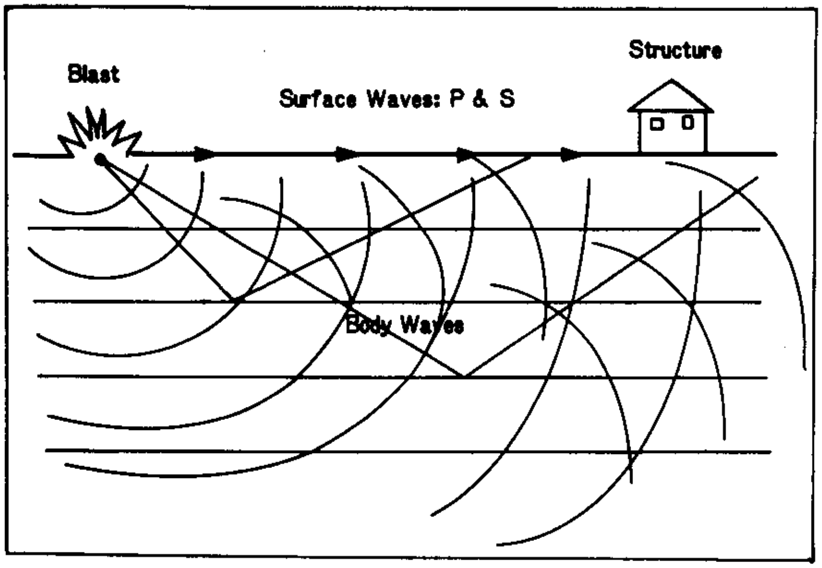

Figure 6.
Surface and body waves.

Particle motion is generally classified into two broad divisions; body waves and surface waves, as shown in Figure 6 on the previous page. Body waves may be reflected or refracted to the surface to become surface waves. Further classification will identify Rayleigh waves, with a circular or rotational movement and also 'p' waves - compressional waves - and 's' waves that have a shearing action (Figure 7). Ground motion consists of a combination of all these wave forms. This manual does not intend to discuss this subject in detail, but will refer to it briefly, in terms of possible damage effects.

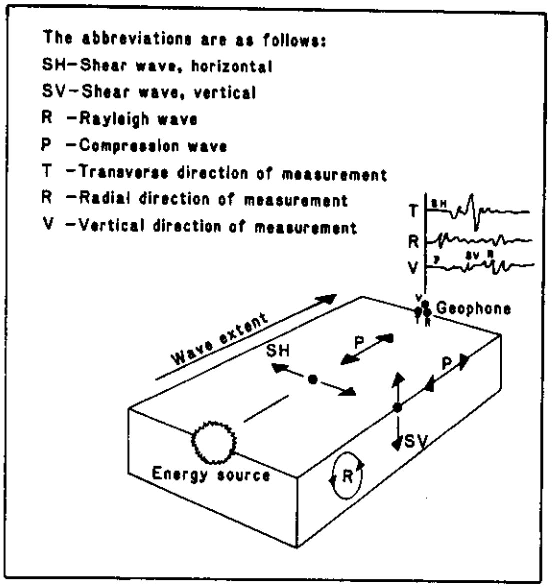

Figure 7.
Types of Ground Motion vibrational waves.

The ways in which these waves can affect buildings and structures on the surface, through compression and tension, and through vertical and horizontal shearing effects, are illustrated in Figure 8, opposite.

There are several ways in which the intensity of these waves can be measured:

DISPLACEMENT is the actual distance over which a particle moves when set in motion by a seismic wave. It is the basic rationale in the 'sloped' portions of the Blasting Level Chart [(Section 816.67(d)(4)(i), see Figure 1 (Manual Figure 12) in Chapter 3, page 24 of this manual] below 4 Hz and between 11 and 30 Hz. It is rarely used nowadays as the sole parameter for ground motion.

VELOCITY is the speed attained by any individual particle during the course of its oscillatory motion, and in the past this has been determined to be the most significant single parameter, in terms of damage possibility. Langefors and Kihlstrom in Sweden, Edwards and Northwood in Canada, and in the United States, the USBM (Bulletin 442 and 665; RI 8507 and 8896) have all used Peak Particle Velocity as the fundamental and principal damage possibility parameter. There is no doubt whatever, in spite of some ongoing argument, that the Peak Particle Velocity, considered in conjunction with the the frequency and duration of the blast vibration, is the most appropriate and accurate indicator of possible blast damage. Incidentally, Seismic or Propagation Velocity is the velocity at which a wave passes through the earth, and must not be confused with Particle Velocity. The two are easy to distinguish: seismic velocity is very fast, thousands of feet per second, while particle velocity is very slow, even damaging particle velocities being measured at only a few inches per second.

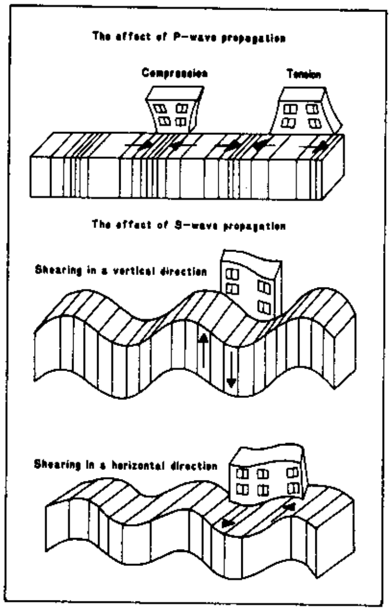

Figure 8.
Compression, tension and shearing effects.

ACCELERATION is the rate of increase in velocity of a vibrating particle, as it oscillates about its rest position. In some instances, acceleration is of interest in terms of blast vibration, but it does not generally concern surface coal mining, unless blasting is carried out close to electro-mechanical devices, relays, tape systems or computer installations, which are sometimes specified for a maximum acceleration level.

Figure 9, overleaf, shows the relationships between these three basic blast vibration parameters. These relationships also introduce frequency as a common variable factor. Frequency alone is of no consequence, but when considered in conjunction with either particle velocity or displacement, recent studies have shown that frequency has a very considerable effect on the possibility of blast vibration damage. USBM publications RI 8507, and the work of Dr. Kenneth Medearis, both stress the importance of frequency, while the present OSMRE regulations on scaled distance and maximum peak particle velocity are based on the effects that low frequencies have on damage possibilities, when using peak particle velocity as the basic parameter.

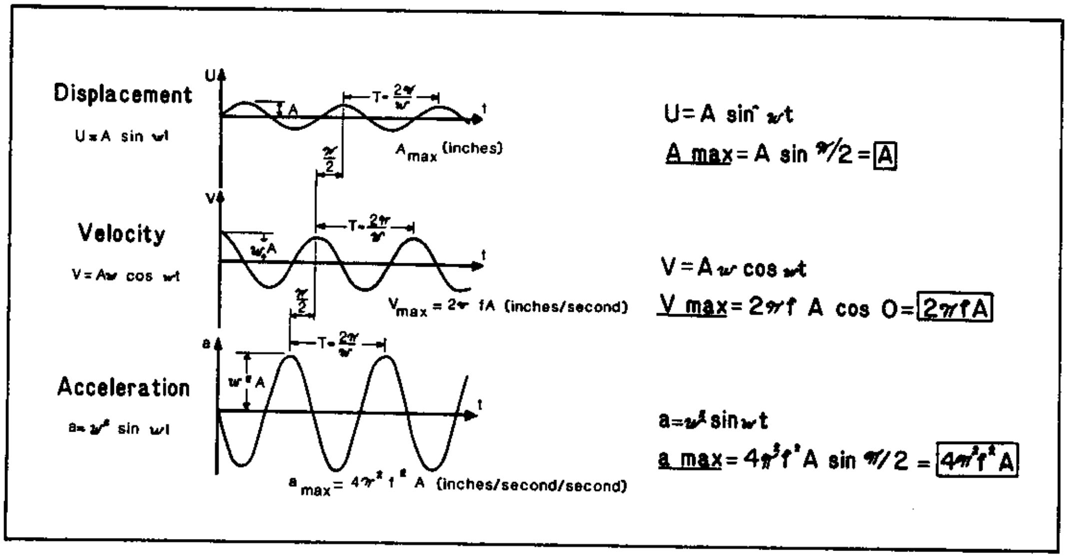

Figure 9.
Vibration parameter relationships.

Vector sum, or resultant velocity, is not normally used as a parameter any longer. Some instruments still show resultant velocity, instead of the maximum of any plane. This will present no problem in terms of simple compliance, since a vector sum, if not equal, will always exceed the maximum in any plane. Some authorities still write specifications in terms of "ENERGY RATIO" which is calculated from a true resultant velocity. This should not normally concern the surface coal mine operator; however, as a point of interest, if he should wish to calculate a resultant velocity, a TRUE resultant velocity will be calculated from peak measurements in all three planes, WHICH WERE RECORDED AT THE SAME INSTANT OF TIME. If the calculation is made from the maximum peaks that occurred in all three planes during the course of the entire event, it will provide the PSEUDO RESULTANT VELOCITY instead.

Formulae for calculating the relationships between peak particle velocity, displacement and acceleration are provided in the "Useful Formulae" Section of Appendix 'A', on page 169.

CHAPTER 3

CONTROL OF ADVERSE EFFECTS

Blasting carried out at surface coal mines, and at some of the entries of, or for facilities at certain underground mines, will always cause some degree of "adverse effects". Just how adverse these effects might be depends on how close the blasting is to people and property. What is adverse in one case may not be in another, and except in the case of flyrock, negative subjective response by the public to the mining operation can be a major factor.

The OSMRE Regulations (Section 816.67(a)) state: "Blasting shall be conducted to prevent damage to persons, damage to public or private property outside the permit area, adverse impacts on any underground mine, and change in the course, channel or availability of surface or ground water outside the permit area."

There are three main adverse effects of blasting:

• Airblast	(Section 816.67(b))
• Flyrock	(Section 816.67(c))
• Ground motion	(Section 816.67(d))

These effects will be discussed together with some typical damage possibilities.

AIRBLAST

Commonly known also as "air overpressure". The Bureau of Mines Publication IC 8925 "Explosives and Blasting Procedures Manual" describes airblast thus: "An airborne shock wave resulting from the detonation of explosives. May be caused by burden movement, or the release of expanding gas into the air. May or may not be audible." If the total energy in the shock wave is low, but the predominant frequencies are well within the range of human hearing (16-20,000 Hz ±) then although a LOUD event might be heard, it might not record very high in terms of dBL or psi. Conversely, a very low frequency event, say predominantly 6 Hz or so, would be virtually inaudible, yet might register very highly as an airblast event, and even possibly cause damage.

The "loudness" of an event is no real indication of how "high" it is or whether or not it could have caused damage.

For years, airblast was considered a minor problem. For example, Bureau of Mines Bulletin 656, for years the industry's standard on blast effects, dealt with the subject on less than ten pages, the subject chapter being only four pages long. Real structural damage resulting from airblast is not only usually minor, but very rare. Window breakage is normally the first and only damage to result from airblast. Subjective response to airblast, however, can make it the most significant of any of the three adverse effects.

Concern regarding noise pollution generally during the early 1970's involved the U.S. Bureau of Mines in a study which resulted in early standards and instrumentation guidelines. During the same period, and preceding the Act of 1977 and the OSMRE regulations, the industry and blast vibration consultants, together with the state agencies, came to realize the importance of airblast. Instrumentation was developed that monitored airblast, together with or separately from ground motion, and standards were defined and consistency developed between states.

The OSMRE Regulations (Section 816.67: Use of Explosives: Control of Adverse Effects) refers to airblast in paragraph (b) which states:

> (b) Airblast - (1) Limits. (i) Airblast shall not exceed the minimum limits listed below at the location of any dwelling, public building, school, church, or community or institutional building outside the permit area, except as provided in paragraph (e) of this section.

Lower Frequency Limit of Measuring system, in Hz.	Max. Level in dB (±3dB)
1 Hz or lower--flat response<1>	134 peak
2 Hz or lower--flat response	133 peak
6 Hz or lower--flat response	129 peak
C-weighted --slow response<1>	105 peak dBC

<1> Only when approved by the regulatory authority.

> (ii) If necessary to prevent damage, the regulatory authority may specify lower maximum allowable airblast levels than those of paragraph (b)(1)(i) of this section for use in the vicinity of a specific blasting operation.

Also to be noted is the requirement that the operator shall conduct 'periodic' monitoring of airblast. [Section 816.67(b)(2)(i)]. To ensure compliance with the airblast standard, this periodic monitoring should at least be on a yearly basis, and should monitor airblast from a typical production shot, under normal weather conditions for the locality, at the mine perimeter or the nearest dwelling, school or church, etc., as stipulated in Section 816.67.(b)(1)(i).

The limits on page 16 are based on the minimal probability of superficial damage to residential type structures, and also take into consideration subjective human response. It is appropriate to clarify here a common cause of confusion and misunderstanding: the frequency ranges shown in the table on page 16 refer to the response sensitivity of the measuring instrument, and not to the predominant frequency of the airblast vibration itself.

When studying these limitations, it might also be remembered that the Bureau of Mines has said that levels exceeding 120 dBL will produce some annoyance from rattling and fright, with up to 10% of homes exhibiting disturbances at 134 dBL (0.1 Hz high-pass). Efforts should be made to try to keep airblast levels to 110 dBL (2 Hz high-pass) in order to reduce annoyance and complaints as much as possible.

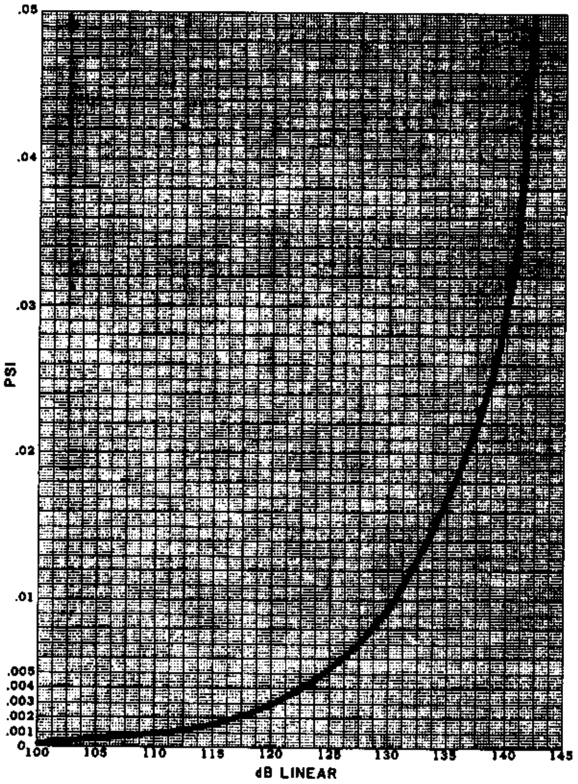

Figure 10.
Relationship between dB Linear and PSI.

Airblast is measured in decibels (dB) which are units of comparison of sound pressure on a logarithmic scale. It is important to understand the significance of a logarithmic scale, which never reaches zero as it goes down, and which increases tenfold for each repeated "cycle" as the scale goes up. It is used when a logarithmic scale permits an "exponential" curve to be drawn as a simple straight line, and also to conveniently compress a wide numerical range scale onto a single sheet of paper. Compared to a linear scaling - like feet or pounds, or miles per hour (see Fig. 10 on the preceding page), one can say that a decibel higher up on the scale is larger - sometimes very much larger - than a decibel lower down the scale. It is not a unit of measurement, therefore, in the same way that a foot or a pound is. Added to this rather complicated concept is the fact that not all decibels are the same anyway: there are certain differences built in called weighting. For example, when decibels are used to measure SOUND (and it has already been pointed out that airblast, not being necessarily audible, is not SOUND as such) the "A" weighted decibel scale is used. This is first because SOUND, a steady-state continuous vibration, is not the short duration impulsive event that airblast is. Secondly, because SOUND is generally perceived by human ears, the "A" weighting emphasizes vibrations at those middle frequencies that the human ear is most sensitive to, and puts less stress on the higher and lower frequencies to which the ear is not sensitive.

As has already been noted, much air overpressure energy, airblast, is at low frequencies. It is therefore usual to adopt the "Linear" or "Flat" weighted decibel scale for all airblast measurements. To avoid further confusion, it must also be explained that dB "Linear" is still a logarithmic scale: dBL are only 'linear' in terms of frequency response. Because of the typically low frequency energy in airblast, the OSMRE Regulations (Section 816,67(b)) table of dB limitations on page 16 allow higher decibel readings when the instrument measuring the vibrations is more sensitive to lower frequencies. Most modern airblast measuring equipment has a flat frequency response down to 5 Hz, a few instruments down to 1 or 2 Hz, though only a very few laboratory type instruments, which require specific OSMRE approval for use in the field, have a flat response down to 0.1 hz.

The following table relates some of the more common instruments to their frequency response and, therefore, to the appropriate OSMRE airblast limitation.

INSTRUMENT:	RESPONSE DOWN TO	OSM LIMITATION dBL
VME LOG II	1 Hz	133
BERGER 1000D	2 Hz	133
VME LOG I	2 Hz	133
VME SOUNDTECTOR	2 Hz	133
DI ST-4-D	2 Hz (optional)	133
DI ST-4-D	5 Hz (standard)	129
DI ST-4	5 Hz	129
DI BT-4-B	5 Hz	129
SINCO S-6	5 Hz	129
VIBRA-TECH GMS-4 Series 2000	5 Hz	129
VIBRA-TECH EVERLERT Series 5000	5 Hz	129
VME Velocity Recorder Model F	5 Hz	129

The foregoing does not imply that if any instrument with a low frequency response is used, a higher and less restrictive airblast limitation applies. The magnitude of the airblast will remain the same; the lower frequency response instrument may simply read higher, dependent on the frequency of the actual airblast.

One of the reasons why OSMRE requires specific approval for the use of very low frequency response instruments is the phenomenon known as "microphonics". Below about 5 Hz, and at sufficiently high overpressures - over 100 dBL or so - it is possible for a signal to be induced by low frequency vibrations in the microphone itself, or in its supports, resulting in the recording of falsely high overpressures. The lower the frequency, generally the more marked this phenomenon is. Great care should be exercised in mounting low frequency response microphones in order to isolate them as far as possible from extraneous vibrations. Rather more susceptible are mast mounted microphones and instruments having metal cases. It does not automatically follow, therefore, that the lower the frequency response, the more suitable the instrument.

A more commonly used expression of air overpressure is pounds per square inch. PSI can be directly converted to and from dBL, and possesses a great advantage over the confusions of dB in that psi is linear, not logarithmic. Direct comparisons are therefore possible: i.e., 0.04 psi is twice as high as 0.02 psi. By contrast, twice 120 dBL is 126.02 dBL, showing that comparisons of this sort should never be made in terms of dB.

dBL = 20 log P/Po, where P = the air overpressure measured in psi, and Po is the reference pressure of 2.9×10^{-9} (0.0000000029 psi), equivalent to 0.0002 microbars.

A further linear scale in common use, and directly equatable with psi, is mb or millibars. The Dallas Instruments (DI) series of instrumentation employs the millibar scale for recording airblast.

When predictive calculations are made with airblast data, the linear psi scale, or the mb scale, are always used; never dB. Conversions can be made to and from the results of such calculations.

The final confusion on dB that should be cleared up concerns the last OSMRE airblast limitation that is shown on the Section 816.67(b) table: "C-weighted-slow response - 105 dBC" The C-weighted scale is normally used for impulsive noise measurements, again specifically in terms of audible noise. This is, therefore, an allowable method of airblast measurement, but it is not usual, and as in the case of instruments with a flat frequency response down to 0.1 Hz, specific OSMRE approval must be obtained for the use of C-weighted-slow response instruments.

FLYROCK

"Rock that is propelled through the air from a blast. Excessive flyrock may be caused by poor blast design or unexpected zones of weakness in the rock." (Bureau of Mines IC 8925/1983, Appendix 'B', Glossary.)

Flyrock is the only one of the three main adverse effects where subjective human response is not of concern. No one ever suffers imaginary flyrock damage. There are few contested flyrock claims: the evidence is usually incontestible except in the case of minor damage to vehicles.

Explosives are used to fragment rock, and even under normal conditions when there is no intent to displace or "cast" the rock, there can be some unwanted displacement or "throw". Flyrock is simply undesirable and excessive throw. It is a greater problem when deliberate displacement, casting, is an objective. In surface coal operations, equipment damage on site, and property damage outside the permit area, can occur. In contour mining particularly, flyrock has caused severe personal injury, and even death, and it has also been responsible for major property damage.

Figure 11.
Explosive Casting.

Control of Adverse Effects

The OSMRE regulations state that flyrock traveling in the air or along the ground (so flyrock does not have to be "flying") shall not be cast from the blasting site:

1. More than one-half the distance to the nearest dwelling or other occupied structure;
2. Beyond the area of control required under Section 816.66(c);
3. Beyond the permit boundary.

The OSMRE Regulations are clear and simple, and are based on preventing the possibility of any flyrock causing injury anywhere, or property damage outside the permit area or beyond the control area. Flyrock being what it is, there is no way that all possibility of damage throughout the mine site can be eliminated, other than by the removal of all vehicles and equipment beyond possible range ("one-half the distance to the nearest dwelling"). OSMRE holds that this is up to the individual mine operator, and not a matter for regulation. This is, of course, quite separate from any safety considerations, which are regulated, and which in other ways ensure personal safety from the effects of flyrock.

GROUND MOTION

"A shaking of the ground caused by the elastic wave emanating from a blast. Excessive vibrations cause damage to structures."

Ground motion is the most frequently cited cause of blast vibration damage, and apart from flyrock, is, in fact, the most likely cause of real damage. It is also a very frequent cause of imagined damage.

Ground motion can cause physical damage to mine plant and structures, and to neighboring residences outside the mine permit area. The most common type of damage associated with excessive ground motion is the aggravation of existing minor cracks.

The subjective perception of ground motion is probably as serious a problem as the possibility of actual physical damage. When subjected to any significant ground motion, the perceptible shaking of a residence will cause some degree of subjective reaction by the occupants of that building. The extent of this subjective reaction can lead to complaints of damage either real or imagined.

Ground motion will not discriminate, either in terms of cause or effect. All structures or facilities surrounding a blast site will respond, with the vibration intensities varying only dependent on physical variables such as distance, explosive charge weight per delay, the frequency of the vibration, shot geometry and confinement. Other geological variables may cause significant differences as the site shifts geographically, but at any one particular site - and particularly for one specific blast - the three primary variables are as stated as follows:

- Distance from blasting to position of interest;
- Explosive charge weight per 8 millisecond delay period;
- Frequency of vibration.

These are the fundamental controls, and no single specific site will be more, or less, affected than any other, given the same location. These factors will be discussed in more detail under the headings of "Compliance Options" (Chap. 9), "Prediction and Control Methods" (Chap. 10) and "Frequency Considerations" (Chap. 11).

The OSMRE Regulations (Section 816.67(d)) state:

(d) <u>Ground vibration</u>. (1) <u>General</u>.
In all blasting operations, except as otherwise authorized in Paragraph (e) of this section, the maximum ground vibration shall not exceed the values approved in the blasting plan required under

Section 780.13 of this chapter. The maximum ground vibration for protected structures listed in Paragraph (d)(2)(i) of this section shall be established in accordance with either the maximum peak-particle-velocity limit of Paragraph (d)(2), the scaled-distance equation of Paragraph (d)(3), the blasting-level chart of Paragraph (d)(4) of this section, or by the regulatory authority under Paragraph (d)(5) of this section.

All structures in the vicinity of the blasting area, not listed in Paragraph (d)(2)(i) of the section, such as water towers, pipelines and other utilities, tunnels, dams, impoundments, and underground mines shall be protected from damage by establishment of a maximum allowable limit on the ground vibration, submitted by the operator in the blasting plan and approved by the regulatory authority.

(2) <u>Maximum peak particle velocity</u>. (i) The maximum ground vibration shall not exceed the following limits at the location of any dwelling, public building, school, church, or community or institutional building outside the permit area.

Distance (D) from the blasting site (feet)	Maximum allowable peak particle velocity (Vmax) for ground vibration (in/sec) 1/	Scaled-distance factor to be applied without seismic monitoring 2/
0 to 300	1.25	50
301 to 5,000	1.00	55
5,001 and beyond	0.75	65

1/ Ground Vibration shall be measured as the particle velocity. Particle velocity shall be recorded in three mutually perpendicular directions. The maximum allowable peak particle velocity shall apply to each of the three measurements.

2/ Applicable to the scaled-distance equation of Paragraph (2) of this section.

(ii) A seismograph record shall be provided for each blast.

(3) <u>Scaled-distance equation</u>. (i) An operator may use the scaled-distance equation, $W = (D/Ds)^2$, to determine the allowable charge-weight of explosives to be detonated in any 8-millisecond period, without seismic monitoring; where W = the maximum weight of explosives, in pounds; D = the distance, in feet, from the blasting site to the nearest protected structure; and Ds = the scaled-distance factor, which may initially be approved by the

regulatory authority using the values for scaled-distance factor listed in Paragraph (d)(2) of this section.

(ii) The development of a modified scaled-distance factor may be authorized by the regulatory authority on receipt of a written request by the operator, supported by seismographic records of blasting at the minesite. The modified scaled-distance factor shall be determined such that the particle velocity of the predicted ground vibration will not exceed the prescribed maximum allowable peak particle velocity of Paragraph (d)(2) of this section at a 95-percent confidence level.

(4) Blasting-level chart. (i) An operator may use the ground-vibration limits found in Figure 1. (OSMRE Regulations) to determine the maximum allowable ground vibration.

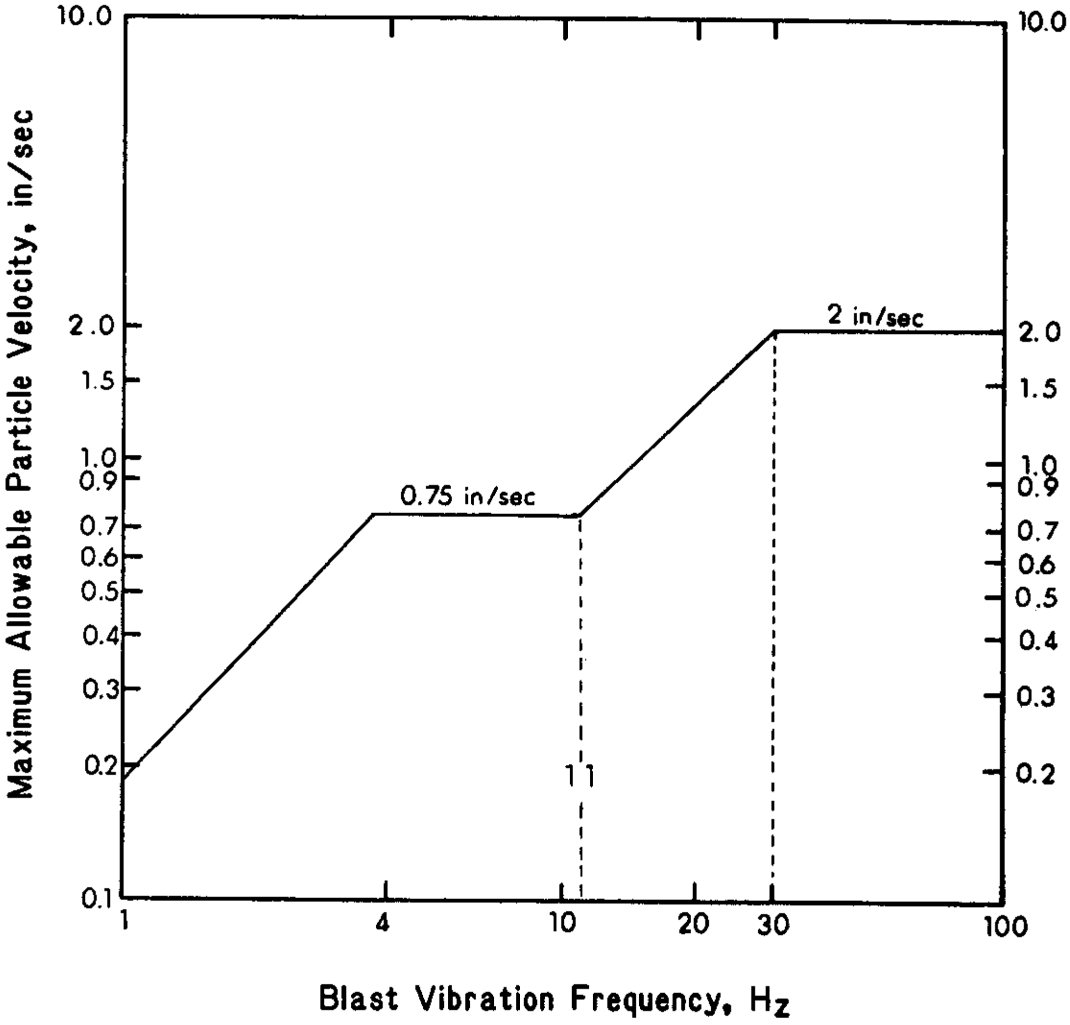

Figure 12. (Figure 1. in OSMRE Regulations)
Alternative Blasting Level Criteria.

(ii) If the Figure 1. (OSMRE Regulations) limits are used, seismographic record including both particle-velocity and vibration-frequency levels shall be provided for each blast. The methods for the analysis of the predominant frequency contained in the blasting recordings shall be approved by the regulatory authority before application of this alternative blasting criterion.

(5) The maximum allowable ground vibration shall be reduced beyond the limits provided by this section, if determined necessary to provide damage protection.

(6) The regulatory authority may require an operator to conduct seismic monitoring of any or all blasts and may specify the location at which the measurements are taken and the degree of detail necessary in the measurement.

(e) If blasting is conducted in accordance with Paragraph (a) of this section, the maximum ground vibration and airblast standards of Paragraphs (b) and (d) of this section shall not apply at the following locations:

(1) At structures owned by the permittee and not leased to another person; and

(2) At structures owned by the permittee and leased to another person, if a written waiver by the lessee is submitted to the regulatory authority before blasting.

These ground vibration regulations are the most complete and complicated of all OSMRE regulations pertaining to blasting. What is not always realized is that they offer the mine operator the option of complying with the ground motion regulations in four different ways, while protecting structures in the area from damage due to excessive vibration:

- Distance related maximum peak particle velocity; assumes that the vibration frequency content decays with distance: no vibration frequency determination required.

- Distance related minimum scaled distance: no vibration measurement or vibration frequency determination required. Not site specific.

- Modified scaled distance. Site specific, based on regression analysis.

- Blasting level chart: this can only be done if both peak particle velocities and frequencies are measured, but this method:

    (a) Permits the most accurate prediction of effects.

(b) Provides the best defense in the event of litigation.

(c) Offers the minimum restrictions on blasting procedures and, therefore, the optimum potential efficiency and cost savings.

Ground motion is normally measured in terms of peak particle velocity, expressed as inches per second. Inches per second represent a linear scale and, therefore, comparisons can be made: 2.0 inches per second is double 1.0 inch per second.

As the vibrations from a blast arrive at a predetermined point, a particle of soil or rock at that point will vibrate, or move randomly in all directions for a short period of time. That is why it is customary to refer to peak PARTICLE velocity, and that is also why such vibrations are measured in three mutually perpendicular planes; to represent, as far as possible, three dimensional vibration.

The base unit for this measurement is velocity. It is the highest velocity that the particle achieves during the course of the event, and can be expressed in inches per second, occurring in each of the three planes, or simply as the highest velocity that occurs in any of them.

The OSMRE regulations (Note 1/ to Section 816.67(d)(2)) require that measurement shall be made in each of the three planes, but that the maximum allowable velocity limits, applicable to each of those planes, can be any one of them. It is not necessary to develop vector sum (resultant) velocity calculations.

The planes of motion referred to above are normally considered to be:

1. LONGITUDINAL: (Sometimes called RADIAL) Measured in a direct line horizontally towards the blast from the point of interest or measurement.

2. TRANSVERSE: Measured horizontally at 90 degrees to the longitudinal plane.

3. VERTICAL: Measured vertically at 90 degrees, therefore, to both the longitudinal and the transverse planes.

These regulations, in that they offer the operator four options in terms of compliance, allow great freedom. When distances and charge weights do not make for critical conditions, then the operator is free to choose the least onerous method - probably simply to adhere to the scaled distance rule. When conditions approach the critical, then the operator could well choose to employ the Figure 1 'Alternative Blasting Level Criteria' (Fig. 12, page 24 in this Manual). At first sight, these may appear to be the most restrictive and complicated, but in fact may well offer the operator the least cumbersome and most efficient answer. This will be discussed in greater detail later in the manual.

FACTORS WHICH CAN INFLUENCE BLASTING VIBRATIONS

Variable factors which can have varying degrees of effect on ground vibration and air blast, both within the control of operators and outside their control, are summarized in Table 1, below, and in Table 2, overleaf, modified from pages 25 and 26 in "Control of Vibration and Blast Noise from Surface Coal Mining", Volume 1, (Wiss, Janney, Elstner and Associates).

GROUND VIBRATION CONTROL

Variables within the control of mine operators	Influence on ground motion		
	Signif.	Moderately signif.	Insignif.
1. Charge weight per delay	X		
2. Delay interval	X		
3. Burden and spacing		X	
4. Stemming (amount)			X
5. Stemming (type)			X
6. Charge length and diameter			X
7. Angle of borehole			X
8. Direction of initiation		X	
9. Charge weight per blast			X
10. Charge depth			X
11. Bare vs. covered primacord			X
12. Charge confinement	X		
Variables not in control of mine operators			
1. General surface terrain			X
2. Type and depth of overburden	X		
3. Wind and weather conditions			X

Table 1.
Factors which influence ground motion.

AIRBLAST CONTROL

Variables within the control of mine operators	Influence on overpressure		
	Signif.	Moderately signif.	Insignif.
1. Charge weight per delay	X		
2. Delay interval	X		
3. Burden and spacing	X		
4. Stemming (amount)	X		
5. Stemming (type)	X		
6. Charge length and diameter			X
7. Angle of borehole			X
8. Direction of initiation	X		
9. Charge weight per blast			X
10. Charge depth	X		
11. Bare vs. covered primacord	X		
12. Charge confinement	X		
Variables not in control of mine operators			
1. General surface terrain		X	
2. Type and depth of overburden	X		
3. Wind and weather conditions	X		

Table 2.
Factors which influence airblast.

CHAPTER 4

DAMAGE

All of the three main adverse effects of blasting can cause damage. However, when the word "damage" is used in the context of blasting effects, the assumption is often made that the blasting in consideration was the direct cause of the damage in consideration. Because of this, it is necessary first to carefully distinguish between the words "damage" and "defect", and then to define just what is meant by blast vibration damage. All houses have defects.

DEFINITION OF DAMAGE

The Bureau of Mines Report of Investigations, RI 8507, 1980, defines damage due to blast produced ground vibration thus:

> "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 than modern gypsum wallboard . . ."

The Bureau's Bulletin 656 (1971) mentions the following indices of damage:

1. Major damage (fall of plaster, serious cracking).
2. Minor damage (fine plaster cracks, opening of old cracks).
3. No damage.

The line that separates real from alleged or imaginary damage is ill-defined. It is therefore very common to talk in terms only of the "probability" or "possibility" of damage. "Damage" itself is a word that can describe anything from a hairline cosmetic crack to a catastrophic structural collapse.

In the context of this Manual, therefore, it must be recognized that except when otherwise defined, all damage references mean minor cosmetic defects: the appearance of small hairline cracks; the lengthening or widening of existing small cracks; paint or plaster flaking or peeling; and, in the case of airblast, simple window glass breakage.

"Probabilities" or "Possibilities" of damage also need careful consideration in order that these terms convey a realistic meaning. RI 8507 (p.49) states: "Analysis of damage probabilities is particularly difficult because of the low probabilities being sought. For example, reliable determination of the 2% damage probability theoretically requires 49 non-damage measurements for every one of damage."

AIRBLAST DAMAGE

There is general agreement among blast vibration experts, governmental regulatory and consultants, that the first damage effects due to airblast take the form of broken window glass. Large, plate-glass windows and shop fronts, etc., are more prone to damage than small glass window panes. Badly set, pre-stressed, or loose panes are more prone to fracture than well set, firm panes that have no stress raisers such as impinging glazier's brads, etc. Structural damage such as plaster cracking due to airblast is not only very rare, but is always accompanied by window breakage.

Airblast frequently causes concern, annoyance, and of course, complaints. Virtually all of the data relating to extensive structural damage due to airblast is derived either from records of nuclear events, or from such calamitous accidents as the Texas City disaster, when an entire cargo of ammonium nitrate on a freighter in the docks detonated in the course of a fire aboard the ship.

Minor cosmetic damage, cracking etc., might occur in conjunction with extensive window glass breakage. Past research has shown that occasional damage to plate glass, which is more damage sensitive than plaster, can occur at approximately 141 dBL (0.0325 psi). Normal size window pane breakage can occasionally occur at perhaps 151 dBL (0.1029 psi) or slightly over.

Annoyance from blasting, which is completely subjective, has no adequate study to assign numbers to. If annoyance from sonic boom produced rattles is considered, it could be said that if airblast can be kept at or below 120 dBL (0.0029 psi) then annoyance will be minimal.

Imagined damage from airblast, because of the highly perceptible nature of this effect, is extremely common.

FLYROCK DAMAGE

Is obvious. As has already been discussed, flyrock does not generally become the subject for argument. It is the one blast-generated cause where minor, cosmetic damage is not in consideration. The common evidence for flyrock damage is a hole in the roof, and a rock on the floor. "Probabilities", or degrees of damage, are not of concern: if flyrock of any significant size contacts a structure, it causes serious localized damage.

Flyrock can cause serious damage, accompanied by obvious consequential problems, to overhead wires: mainly electricity supply, but also to telephone communications. It can also be of concern near microwave antenna installations, repeater stations, and other communication and broadcasting antennas.

"Imaginary" flyrock damage does not occur in the way that imaginary damage is attributed to ground motion or air overpressure. In the case of windshield glass breakage - or hail damage - to vehicles, however, it might be more difficult to differentiate causes. This is one reason why vehicle traffic should be closely controlled within the permit area, and why flyrock should be closely controlled - i.e. prevented - outside it.

The most serious effect of flyrock, quite apart from any possible damage consideration, is of course the fact that, alone among the adverse effects of blasting, flyrock can cause not only serious injury, but death. Ground vibration does not threaten life or limb in this way, nor, under any normal circumstances, does airblast. Flyrock does, and this possibility must always be borne in mind. It is the one ultimate adverse effect of blasting that the surface mine operator must never be guilty of.

GROUND MOTION DAMAGE

Apart from flyrock, this is the most common form of damage due to the three adverse effects of blasting. It is also the most easily and consistently controlled.

Ground motion blast vibration damage is well documented, and points at which threshold damage can occur are the best defined of the three effects.

Failure can occur to brittle materials such as plaster at particle velocities less than 1 inch per second at very low frequencies. The majority of failures will not begin to occur, however, until vibration levels exceed 3 to 4 inches per second.

The table on the next page, derived from Table A-2, Appendix 'A' to RI 8507, shows an interesting comparison between the vibration levels at which various degrees of damage may occur, and the type of terrain or rock on which a structure is built. It is based on the work of U. Langefors and B.K. Kihlstrom:

Damage

	PEAK PARTICLE VELOCITY:INS/SEC.		
DAMAGE EFFECTS:	SAND, GRAVEL, CLAY BELOW WATER LEVEL; c=3000-5000'/sec[1]	MORAINE, SLATE OR SOFT LIMESTONE; c=6000-10000'/sec[1]	GRANITE, HARD LIMESTONE OR DIABASE; c=15000-20000'/sec[1]
NO NOTICEABLE CRACK FORMATION	0.71	1.4	2.8
FINE CRACKS AND FALLING PLASTER THRESHOLD	1.2	2.2	4.3
CRACK FORMATION	1.6	3.2	6.3
SEVERE CRACKS	2.4	4.5	9.1

[1] Propagation velocity in media is given by c.

It is clear, therefore, that the possibility of actual threshold damage is dependent not only on the peak particle velocity, but also on the frequency content of that vibration, and on the type of terrain or rock upon which the structure stands. It is also dependent on the type of structure, the height of the structure; the natural frequency of the structure, and of course, on the state of repair - or disrepair - of the structure. Even when that structure can be said to be in a good state of repair, it might also be that it is old, or that it has some particular historic significance. Factors such as this dictate special considerations, perhaps specific velocity limitations.

It is also clear that some of these conditions may combine so that even if actual damage is unlikely below 2 or 3 inches per second, it is nevertheless POSSIBLE that threshold damage might occur under some conditions at velocities as low as 0.5 to 0.7 inches per second. Notwithstanding the great volume of opinion and evidence showing that relatively high vibration levels are necessary to cause damage, it is also quite clear that the OSMRE regulations impose very realistic limitations. Recalling the intent of the Act, the regulations provide positive protection against damage to private and public property.

A frequently heard argument from complainants is based on the belief that if a single event may not damage the structure, then multiple events must have a cumulative effect. They therefore base their damage claim not on the effects of isolated events, but on the effects of repeated blasting.

The Bureau of Mines recent Report of Investigations, RI 8896, 1984, deals precisely with this common misapprehension. A test house was built in the path of an advancing surface coal operation so that it could be thoroughly studied in terms of repeated blasting effects. Structural fatigue and damage were studied over a two year period, during which time the house was subjected to 587 production blasts, the peak particle velocities ranging from 0.10 to 6.94 inches per second. Following this blasting effect study, the entire house was shaken mechanically to produce fatigue cracking.

Cosmetic or hairline cracks 0.01 to 0.10 mm wide appeared during construction of the house, and also during a period when no blasting was taking place. The formation of cosmetic cracks increased from 0.3 to 1.0 cracks per week when ground motions exceeded 1.0 inch per second. Human activity and changes in temperature were equivalent to those produced by ground motions up to 1.2 inches per second.

When the entire house was shaken mechanically, the first cracks appeared after 56,000 cycles, the equivalent of 28 years of blast generated ground motions of 0.5 inches per second, twice a day.

If blasting occurred only once a day, this would be equivalent to a period of 56 years; if blasting was only once a week, then it would equate to blasting for a period of 392 years!

Activity	Location[1]	Induced strain (μin/in) or structure motion (in/s)	Ground vibration equivalency, (in/s)	
			Envelope[2]	Regression line[3]
Walking.......	A4, low corner, south wall.	0.16 in/s.....	0.07	0.29
	A4, low corner, east wall.	0.039 in/s....	.005	.07
	S2............	9.1 μin/in....	.03	.09
Heel drop.....	A4, low corner, south wall.	0.14 in/s	.06	.24
	A2, midwall...	0.65 in/s.....	.06	.17
	S2............	20 μin/in.....	.03	.20
Low jump......	A4, low corner, south wall.	0.12 in/s.....	.05	.18
	A2, midwall...	1.8 in/s......	.26	.92
High jump.....	A4, low corner, south wall.	0.31 in/s.....	.29	.74
	A2, midwall...	1.2 in/s......	.15	.52
	S2............	42 μin/in.....	.28	.62
Entrance door slam.	A4, low corner, east wall.	0.18 in/s.....	.09	.22
	A3, midwall...	1.3 in/s......	.13	.52
	S8............	21 μin/in.....	.27	.60
Sliding glass door slam.	A1, high corner, east wall.	.87 in/s......	.51	.90
	S1............	48.8 μin/in...	.50	1.40
Sinking nails for pictures	A4, low corner, east wall.	0.51 in/s.....	.38	.80
	A5, low corner, west wall.	0.67 in/s.....	.59	.89
	A2, midwall...	3.9 in/s......	.92	2.16
	S1............	21 μin/in.....	.18	.41
	S8............	32 μin/in.....	.38	.87
	S12...........	88.7 μin/in...	.88	1.44

[1] From figure 13.
[2] Based on envelope of strain or structure motion versus ground vibration data.
[3] Based on regression line through strain or structure motion versus ground vibration data.

Table 3
Human activities and equivalent ground vibration levels.

Damage

Table 3 on the previous page, based on Table 9, page 35 in RI 8896, shows ground motion equivalencies for common human activities in the test structure -- activities that are repeated many times daily in the normal occupancy of a residential structure.

Human subjective tolerance to vibration levels is such, however, that levels of 0.5 inches per second annoy 5% of the population, so constant attention must be paid to this problem. Careful consideration should always be given to this important subject, which is dealt with in the following chapter. Efforts made in this direction pay dividends, and will not be regretted.

CHAPTER 5

HUMAN SUBJECTIVE TOLERANCE

It has already been stated that this problem does not occur in terms of flyrock. It does occur, extensively, both in terms of airblast and ground motion, although the humans who are suffering from the subjective reaction to these effects are frequently unable to differentiate between them.

One of the first things to recognize is that when blasting operations take place, there is no way by which complaints can be totally eliminated. At any location where the ground motion or air overpressure is perceptible to human beings, there exists a possibility of complaint.

Factors that can affect human subjectivity are:

- The event itself: human perceptibility.
- The frequency (number of events per day or week).
- The time of day.
- The structural response itself.
- The structural condition of the property.
- The degree of activity of the subject.
- The state of health of the subject.
- The state of mind of the subject.
- The position and attitude of the subject: i.e. in bed, prone; on a floor center, sitting, etc.
- The local perception of the operation.
- The history of local damage claim payments.
- The history of "good neighbor" payments or assistance, related to damage claims where liability was denied.

Additional to the above factors, which all respond to genuine subjective human reaction, is the underlying possibility that human cupidity must be considered. Particularly when a structure has suffered deterioration that could be costly for the owner to correct, allegations of blast vibration damage are frequently made. Interrogation by experienced personnel will often leave such a complainant completely unshaken in his apparent conviction that the blasting activity was the cause of his misfortune. Such cases, even when the technical evidence is overwhelmingly clear that blast damage could not have occurred, can be a persistent problem. Good adherence to OSMRE regulations, complete blasting records, and above all specific blast vibration measurement records will stand the conscientious operator in good stead in such situations.

Whereas the OSMRE regulations do not specifically address these problems of human subjectivity, they do in fact provide a considerable measure of protection against them. The most effective protection is provided by those options that include actual vibration level monitoring and recording. At great distances, of course, these problems are unlikely to arise, and the scaled distance rules may usually be adopted. Bearing in mind, however, that complaints cannot be totally eliminated, it is perhaps timely to note that blast vibration complainants have threatened litigation when scaled distances have been in excess of 200, and instrumentation has been scarcely able to record the effects. One case is known when the scaled distance was in excess of 1000!

Figure 13.
Good Public Relations efforts assist subjective problems.

Human Subjective Tolerance

At what level are human beings able to perceive blast vibration effects? Airblast is extremely difficult to define in this way, because of the very variable audibility of any particular event. If the predominant frequency of the event is low, it could be that, say, 115 dBL might be unnoticeable, whereas if the predominant frequencies were well into the range of human hearing, this same event might be quite annoying. It is also possible that where the airblast frequencies match the natural frequencies of structures, secondary vibrations producing rattling, etc., can occur. This effect can not only increase the subjective perception of an event, but can also extend its apparent duration. Ground motion, on the other hand, while frequency dependent to a point, depends much on the sensitivity of the human subject. Most authorities agree that the threshold of human perception for blast vibration ground motion is around 0.03 inches per second. Depending on activity, sensitivity, and whether or not the subject knows when the event is to occur, a few humans can sense ground motion as low or lower than most instruments are able to: about 0.01 inch per second!

Although complaints <u>can</u> occur at any level perceptible to humans, they are unusual below 0.08 inches per second or so. As peak particle velocities increase and as local and individual sensitivities increase, so will the number of complaints. At, say, 0.25 inches per second, a level that is eminently safe, and well within OSMRE limits, except below 2 Hz, complaints can be expected.

CHAPTER 6

CAUSES OF EXCESSIVE ADVERSE EFFECTS

Apart from the control methods that are discussed in Chapter 10 of this manual, consideration of some of the basic causes of excessive adverse effects will permit simple practical controls that will minimize these problems at the outset.

AIRBLAST

The four primary causes of airblast are generally recognized to be:

- The Air Pressure Pulse: caused by direct rock displacement at the free face or mounding at the borehole collar.
- The Rock Pressure Pulse: caused by vibrating ground.
- The Gas Release Pulse: caused by gas escaping from the detonation through fissures in the fractured rock.
- The Stemming Release Pulse: caused by gas escaping from blown-out stemming.

A further cause that can lead particularly to more highly audible airblast is the presence of uncovered detonating cord on the surface of the shot.

Terrain - normally outside the control of the blaster except perhaps to a very limited extent - will also have an effect on airblast. Terrain can have a mitigating effect when it acts as a barrier, but also, when it takes the form of a reflecting surface, it can materially increase the effects.

Weather - again normally outside the control of the blaster - has also a very marked effect. Atmospheric variables alone account for the great difficulty of predicting airblast effects by means of regression analysis, a technique that is highly effective when applied to ground motion. Figures 14 - 17 overleaf illustrate the highly variable effects of weather conditions: these show inversion effects alone, without considering the additional and considerable effects of wind direction and velocity. Couple those variables with the effects of terrain and it can be readily understood why air overpressure is most difficult to predict with any degree of consistency: any exercise of this sort should be undertaken only with great caution. This is not to say it cannot be done, but the limitations of such predictions should be fully understood, and the conditions carefully specified.

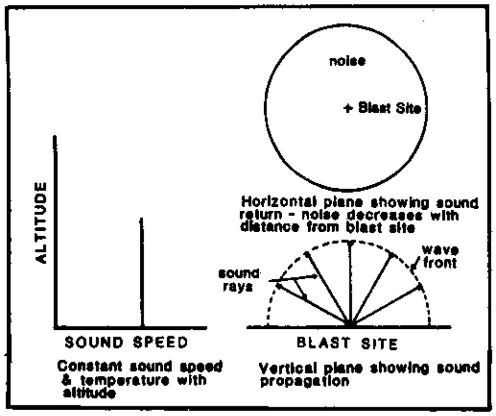

Figure 14.

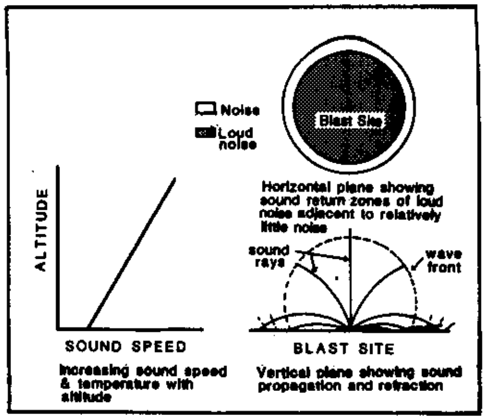

Figure 15.

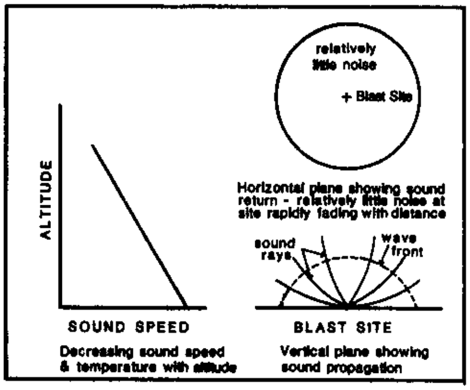

Figure 16.

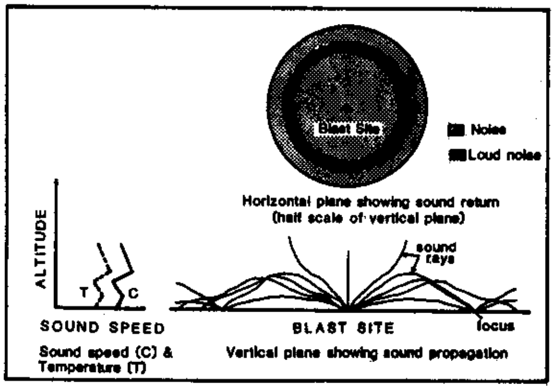

Figure 17.

(Figures 14 to 17 courtesy of E.I. du Pont de Nemours & Co.)

If airblast effects can present problems, then because of unfavorable atmospheric variables, blasting should be avoided, when possible, during the following conditions:

- During a temperature inversion, indicated by hazy, low visibility days with little or no wind.
- During the strong winds that accompany the passage of a cold front.
- When the surface temperature is falling.
- Early in the morning, or after sunset, on clear days with light winds.

- On overcast days with a low ceiling, particularly during calm conditions.

At all times, when the control of airblast becomes of importance, particular attention must be paid during the blast design to:

- Covering up all exposed detonating cord with at least a foot thickness of spoil. Heavier detonating cord will require deeper burial.
- Proper stemming to an adequate depth. Drilling cuttings are not a good stemming material, nor is the sometimes recommended damp sand. The best stemming material is coarse (1/4" to 3/8") dry, sharp gravel.
- Proper burden and spacing.
- Mud seams, voids, etc., should be noted, and proper precautions taken such as decking or stemming through.
- Re-orienting any high free face away from populated areas, if possible.
- Proper choice of delays.
- Atmospheric variables, as discussed above: avoid blasting whenever winds are blowing from the blast site towards populated areas.
- Time of shots: if possible, shots should be fired during periods of high human activity. The noon hour, or after school is out are typically suitable times. Avoid blasting during quiet periods, say, when senior citizens have retired for an afternoon siesta.

Figure 18.
Proper stemming effectively reduces airblast.