U.S. DEPARTMENT OF THE INTERIOR OFFICE OF SURFACE MINING RECLAMATION AND ENFORCEMENT DIRECTIVES SYSTEM	Subject Number: TGR - 1 Transmittal Number: 315 Date: 1/28/87

Subject: OSMRE Blasting Guidance Manual

Approval: [signature] 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.

   OSMRE, WFO, Standards and Evaluation Branch, Michael Rosenthal, Chief, (303) 844-2756, (FTS) 564-2756.

BLASTING GUIDANCE MANUAL

By Michael F. Rosenthal and Gregory L. Morlock

With contributions by John L. H. Simmance,
James W. Reil, G. Alan Foster,
Thomas W. Novotny, and Dennis A. Clark

March 1987

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

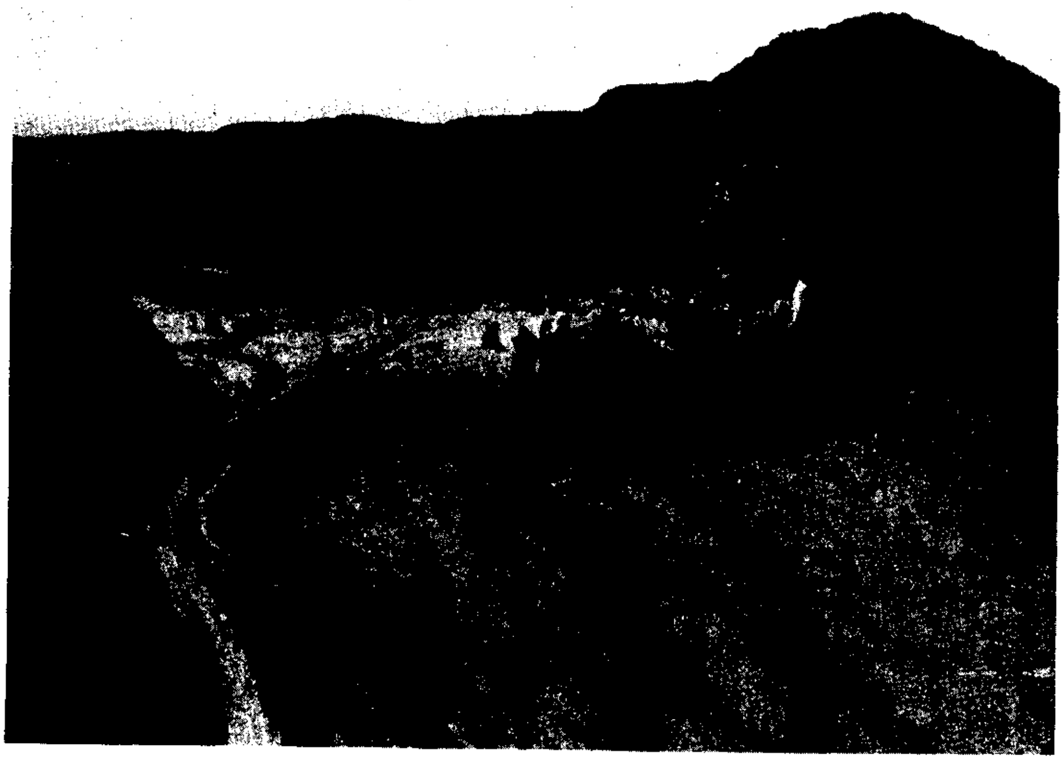


Figure 1.
Surface Mine Blasts.

TABLE OF CONTENTS

ILLUSTRATIONS AND FIGURES

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.

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.

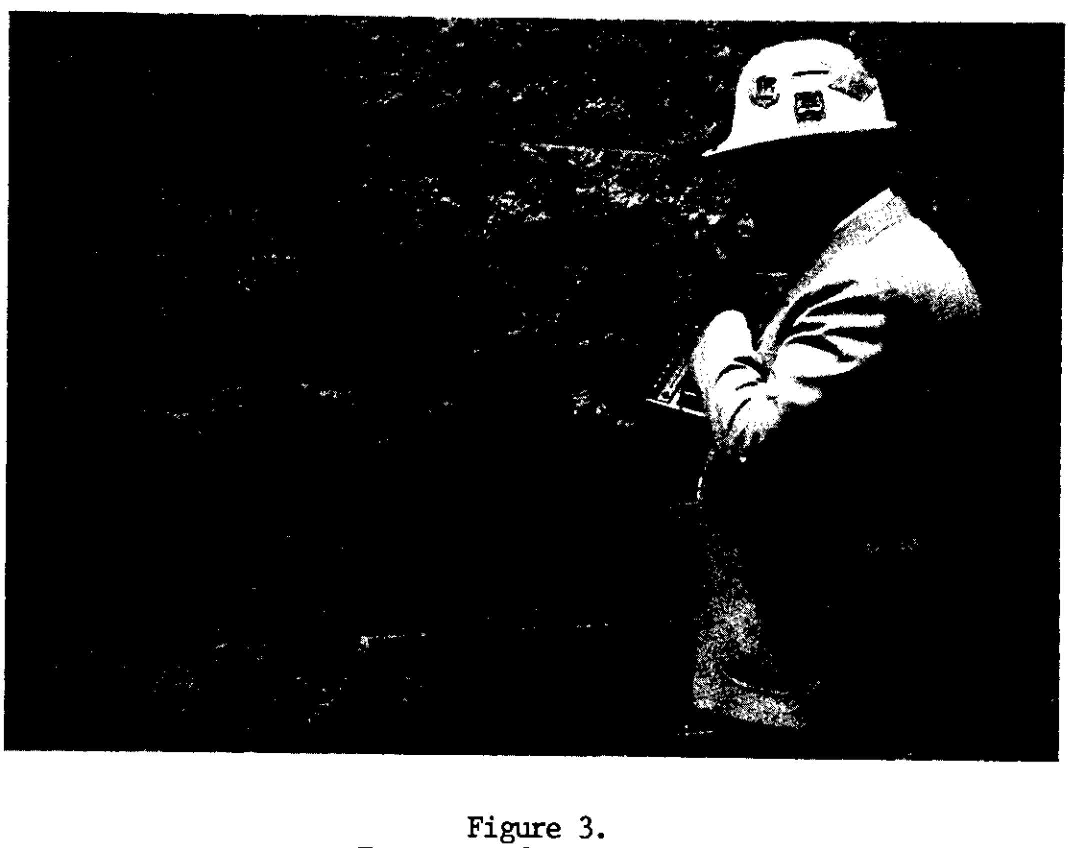


Figure 3.
Tape recording defects.

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.

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

A Member of the Nitro Nobel Group

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. SHEET______ OF______

FIELD REPORT
EXISTING STRUCTURAL CONDITIONS

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: __________

COL-2 (79)

Figure 5.

Pre-Blast Surveys

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.

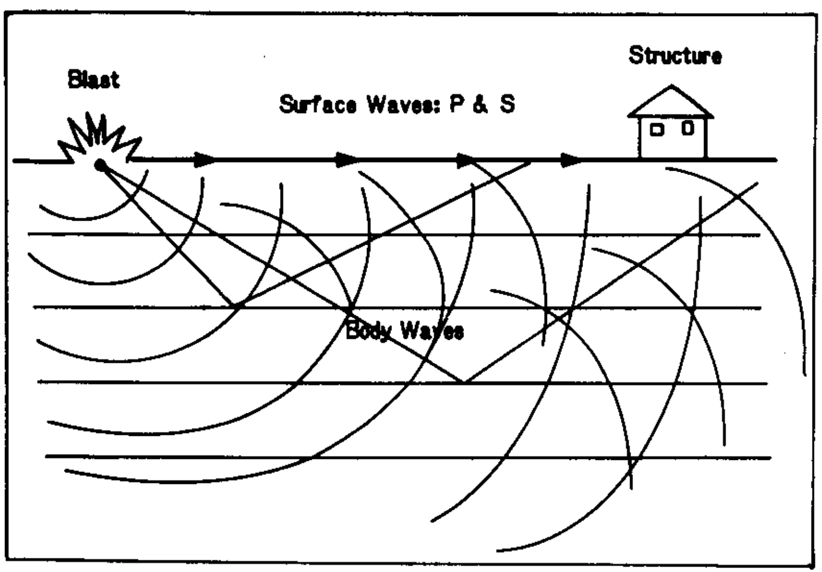


Figure 6.
Surface and body waves.

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.

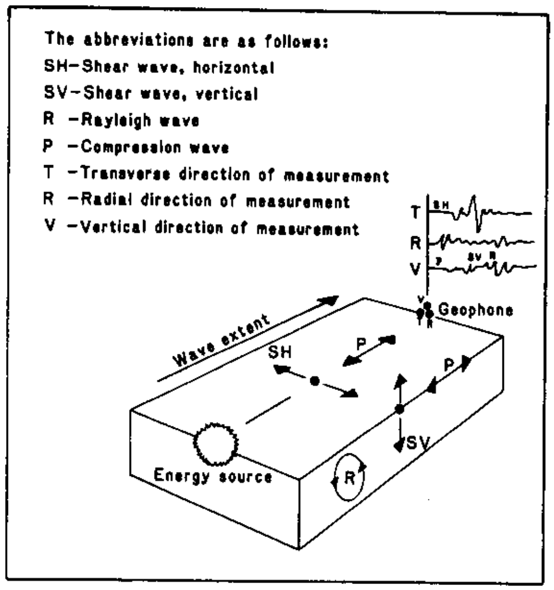


Figure 7.
Types of Ground Motion vibrational waves.

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.

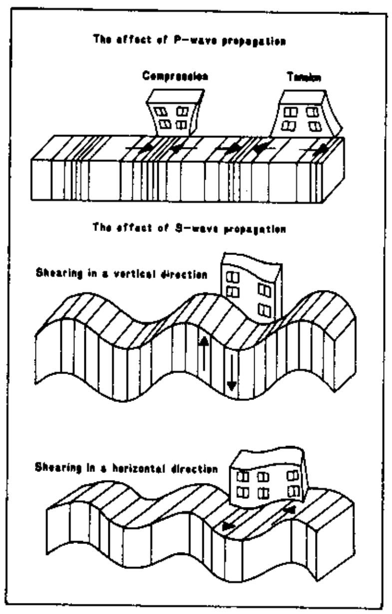


Figure 8.
Compression, tension and shearing effects.

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.

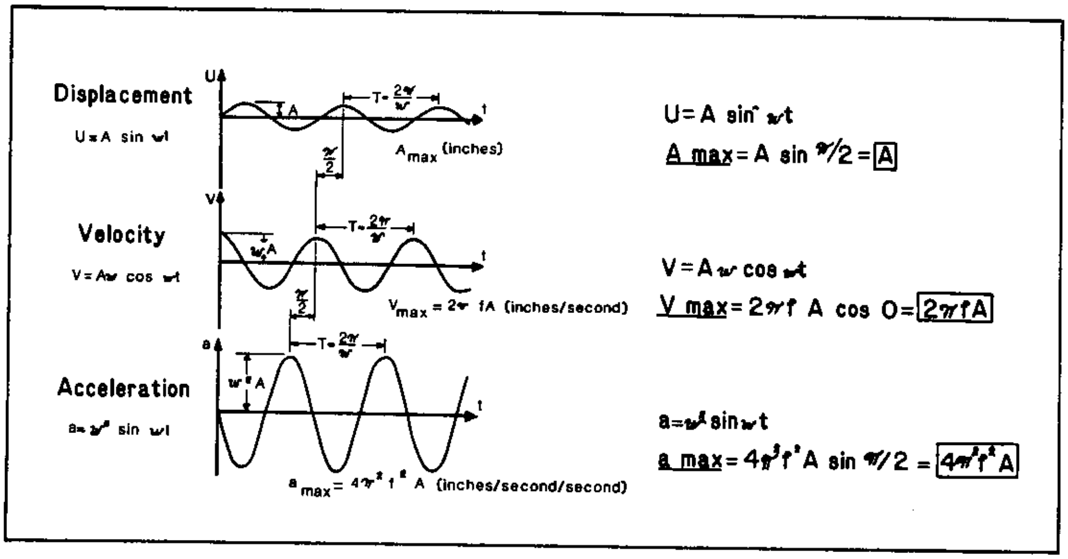


Figure 9.
Vibration parameter relationships.

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.

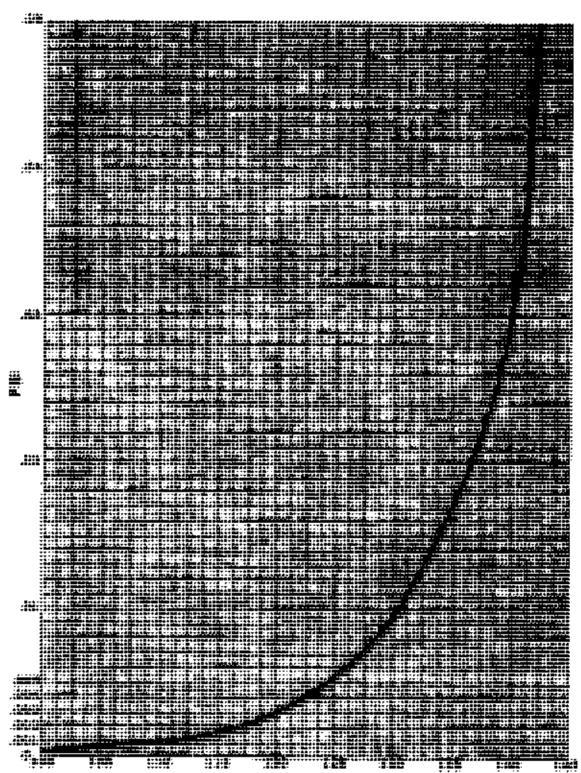


Figure 10.
Relationship between dB Linear and PSI.

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 <u>higher</u> 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) Maximum peak particle velocity. (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) Scaled-distance equation. (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.

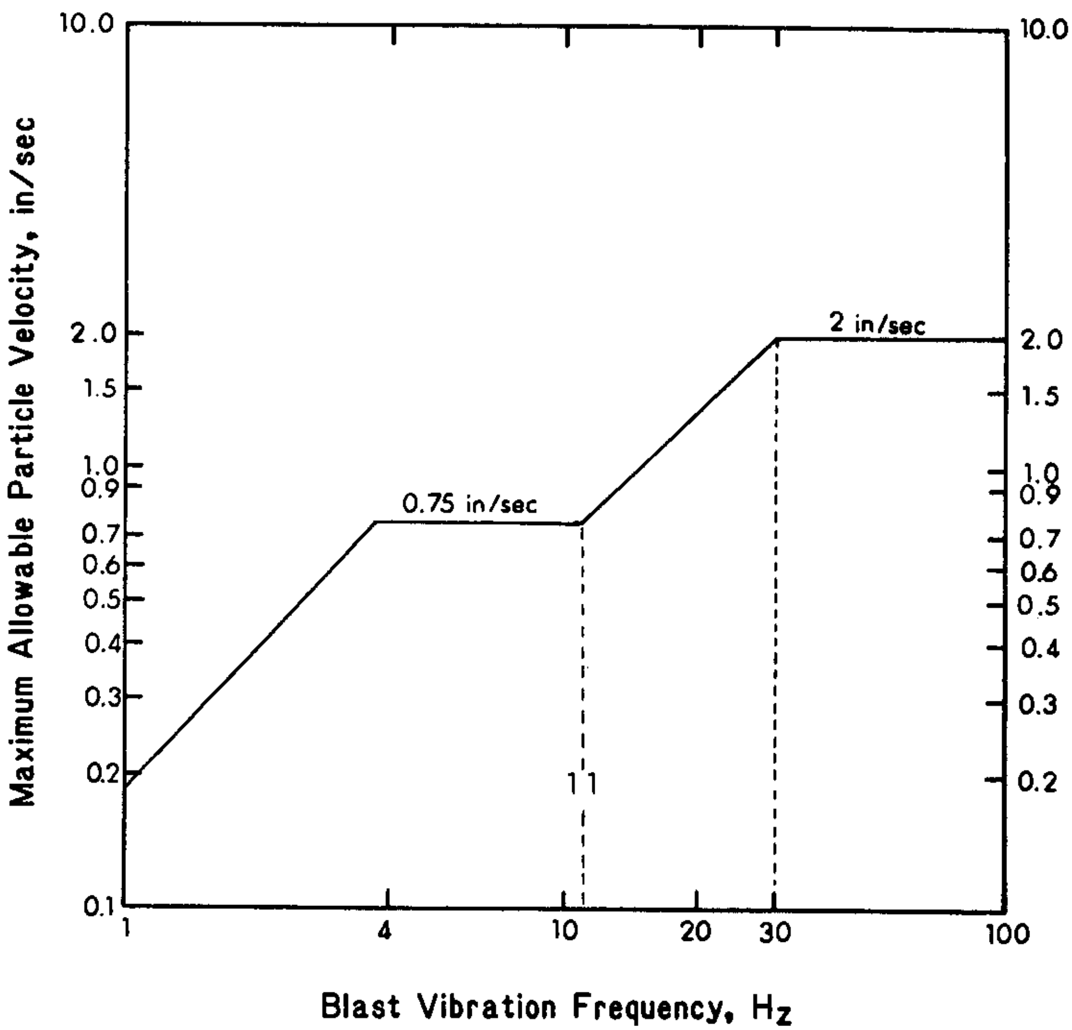


Figure 12. (Figure 1. in OSMRE Regulations)
Alternative Blasting Level Criteria.

(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:

	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 LIME-STONE 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.

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.

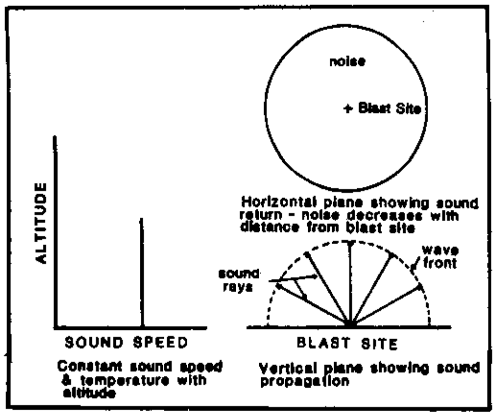


Figure 14.

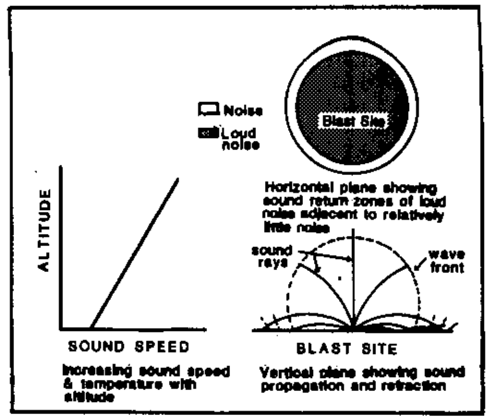
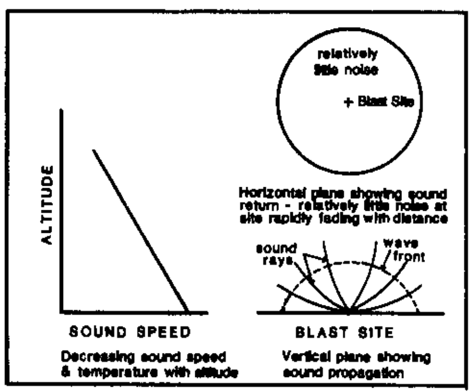


Figure 15.



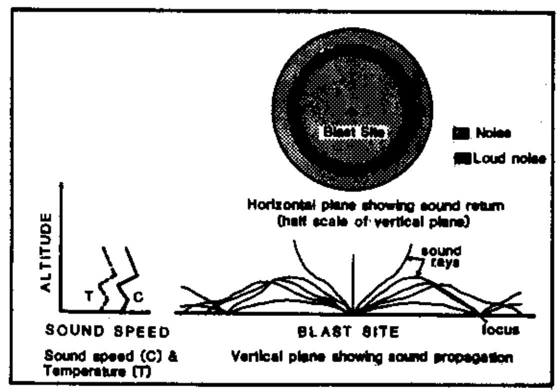


Figure 16. Figure 17.
(Figures 14 to 17 courtesy of E.I. du Pont de Nemours & Co.)

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.

Attention to the above points - which are virtually the only ones the blaster has any control over anyway - will minimize problems due to airblast. To a great extent the stemming release pulse can be controlled, as can, to a rather lesser degree, the gas release pulse. Apart from terrain and weather variables, this only leaves the dominant effects of the air pressure pulse, and to a lesser extent, the rock pressure pulse. Since these both tend to be at lower and less audible frequencies, the overall impact of airblast will be greatly reduced.

FLYROCK

Flyrock occurs when the blast is improperly designed or loaded. Incorrect burden for the explosive load and the geology assures a flyrock problem. A burden too small for the drill hole size and rock type could result in fly from the face. In the same manner, excessive burden or rows of holes without relief will result in violence in the collar zone. Loading holes through zones of weakness, or into voids, will result in "blow outs". Flyrock can also be caused, or contributed to, by geological conditions which can not always be detected prior to the shot.

One technique that is receiving particular attention these days is "casting". This is, as has already been stated, the deliberate use of explosives not merely to fragment the rock, but to move overburden to a spoil pile without, or with minimal rehandling. The mine is trying to control and direct the throw of material so that as much as 65% of the overburden is displaced to the spoil pile. By the controlled application of some of the causes of flyrock, the mine can move large volumes of material. Poor application of casting techniques will result in adverse effects, with flyrock being the greatest, closely followed by excessive airblast.

The main control that can be applied to the blast design is to ensure proper burden and stemming, together with loading the explosives into the borehole to place the energy release at the points where it is required to break the rock. Generally, it is considered that a burden dimension less than 25 times the diameter of the explosive charge can result in long flyrock distances, while excessively large burdens can cause violence in the collar zone (Bu. Mines IC 8925, p.77). Where blasting must take place, and it is difficult to ensure proper burden and stemming relationships, then blasting mats or spoil cover must be used to control flyrock. The above considerations together form the best control solutions to the flyrock problem.

Flyrock and airblast are closely related, and proper techniques to control flyrock will greatly assist in reducing airblast problems. By knowledgeable placement of the explosive in relationship to the face, the collar, and to the known zones of weakness, flyrock can be effectively controlled.

GROUND MOTION

Excessive ground motion is caused by improperly designed blasts, excessive - or insufficient - explosive charge weights, excessive confinement and too short time periods between successive delays.

The fundamental control available to blasters has for years been based on the simple relationship between charge weight and distance. Reducing the charge weight, or increasing the distance, or both, results in a smaller ground vibration. Since confinement and breakage also have a very considerable effect, the above is an oversimplification, but if it is also stated that excessive ground motion equates to wasted energy, it is easier to visualize the following:

A properly designed blast will give lower ground motion per pound of explosive than one that is poorly designed. For a given weight of explosive that is detonated, a certain fixed amount of energy is released. If that energy is used in breaking rock into fragments, there is less "waste energy" available at the end of the reaction to go into the ground as excess vibration. A badly designed shot, where good breakage is not obtained, will generally produce higher levels of ground motion. This fact must also be remembered when specifically high confinement shots are being designed (e.g. pre-splitting) because in these cases any "site-specific" attenuation formula that has been developed may not apply. In fact, when developing such attenuation formulas for any particular mine site, it is normally necessary to divide data into groups: "OVERBURDEN", "COAL" and "OVERBURDEN PRE-SPLIT", etc. Separate formulas would have to be developed for each category. This subject will be discussed fully in Chapters 9 and 10.

The U.S. Bureau of Mines, in IC 8925, outlines the following five techniques that can be used to minimize ground motion:

1. Reduce the charge weight of explosives per delay period. This is most easily done by reducing the number of blastholes fired on each delay. If there are not enough delay periods available, a sequential timer blasting machine can be used, or a combination of surface and in-hole nonelectric delays. The manufacturer should be consulted for advice when using the sequential timer or complex delay systems. If the blast already employs only one blasthole per delay, smaller diameter blastholes, a lower bench height, or several delayed decks in each blasthole can be used. Delays are often required when presplitting.

2. Overly confined charges such as those having too much burden or too much subdrilling should be avoided. The primer should not be placed in the subdrilling. Where it appears that a later row of blastholes will not have adequate relief, a delay period should be skipped between rows.

3. The length of delay between charges can be increased. This is especially helpful when firing large charge weights per delay at large blast-to-structure distances. However, this will increase the duration of the blast, and may cause more adverse reactions from neighbors.

4. If delays in a row are arranged in sequence, the lowest delay should be placed in the hole nearest the structure of concern, except at very short distances when other considerations apply. In other words, the shot should normally be propagated in a direction away from the structure.

5. The public's perception of ground vibrations can be reduced by blasting during periods of high local activity, such as the noon hour, or shortly after school has been dismissed. Blasting during typically quiet periods should be avoided, if possible.

Very recent research ("Geologic Factors Affecting Vibration from Surface Mine Blasting", USBM 1985, See Bibliography) has shown that it is possible to reduce ground vibration levels, particularly low frequency vibrations, by the proper selection of delay periods. Firing times are chosen by analyzing the vibration response created by the detonation of a single blasthole. This response is a function of the geology at the blast site, the vibration travel path, and the geology at the recording location. Blast firing times can be selected to create "out of phase" vibrations with adjacent holes. Significant reduction of vibration levels (up to 50%) have been achieved in controlled tests.

Tables 1 and 2, pages 27 and 28 in Chapter 3, summarize the factors which influence ground motion and airblast to one extent or another. The influence might be to increase or decrease the effect of the vibration, as in the case of confinement. Highly confined blasts will tend to produce high ground vibrations and low airblast. Unconfined blasts will cause low levels of ground motion, but very high overpressures, with high frequencies, audible over long distances.

CHAPTER 7

VIBRATION MONITORING

The Bureau of Mines Reports of Investigations, RI 8506 and 8507 are the current standards for defining methods of monitoring ground motion and airblast respectively. There are many different monitoring instruments available; some used more in a research capacity, and others used basically for compliance and effect control. In this chapter, and in the later chapter devoted to instrumentation, focus will be upon the specialized instruments produced specifically for blast vibration compliance and control. The majority of these instruments are portable.

AIRBLAST MONITORING

The basic choices open to the operator are:

- Peak only vs. entire time history recording instruments.
- Permanently or semi-permanently installed vs. portable, operator set-up and/or attended.
- Monitoring by consultants.

Any instrument with a frequency response listed within the requirements of Section 816.67(b) can be used, and because the OSMRE regulations regarding airblast do not relate to the predominant frequency of the airblast itself, peak reading instruments alone are satisfactory for compliance. In instruments which also record ground motion, the airblast may be reported simply as a peak instead of a full waveform. It may be, however, that instruments that record the entire time history waveform would be considered to be preferable, since:

- A waveform of the entire event can frequently help to identify causes of excessive airblast.
- A waveform, by its "signature", can permit discrimination between blast and non-blast overpressure events. This can be of particular importance where remotely installed "constant-recording" instruments are concerned.

Permanently installed "constant-recording" instruments can be more convenient than portable operator attended or set-up instruments. They do not require the labor expense of an operator. They will record any event of a recordable magnitude (generally over about 100 dBL) if they are of the peak recording type, and any event over a preset trigger threshold level if they are of the acoustic/seismic triggered variety. This is an advantage in favor of the peak recording instruments, and a slight disadvantage of the automatically triggered instrument - certainly if it is considered desirable that every event, no matter how minor it might be, should be put on rēcord.

This last disadvantage of triggered instruments may not be immediately apparent. However, if it is remembered that complaints can and will arise from any humanly perceptible blasting event, and that in such circumstances (for the unit failed to receive the minimum vibration that would have been necessary to trigger it) the total lack of a record may prove difficult to explain to an attorney. A flat trace, supported by testimony that the instrument was operating at the time of the blast, is at least a record, albeit of non-measurable vibration. This can be of real value when a complaint situation is at issue.

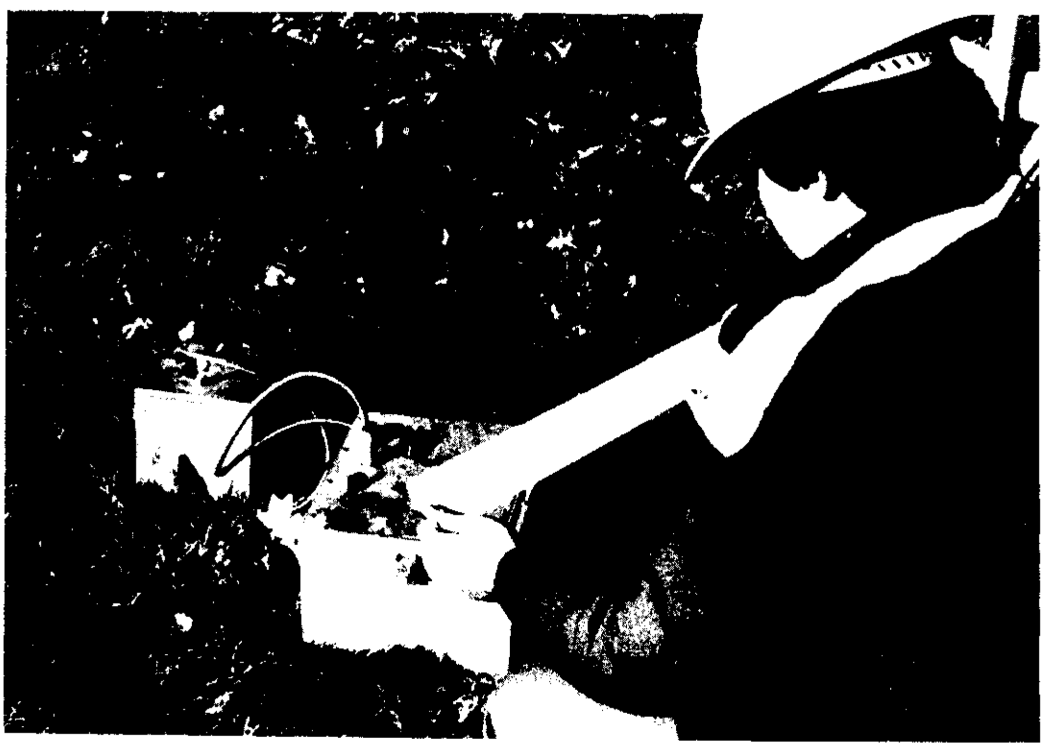


Figure 19.
Field Monitoring.

Portable operator-attended instruments require someone to set them up at a specific location, and to retrieve them following the blasting event. They do not necessarily require critical timing, nor do they always require the operator to be physically present during the actual shot, particularly the magnetic tape recording instrument which will run unattended for up to a half hour or so. Some of these portable instruments can also be of the seismically or acoustically triggered variety, though at closer distances, missing a shot due to non-triggering is normally less of a problem. Nevertheless, care has to be exercised to ensure that the trigger threshold level is set appropriately: nct so high that there is a risk of missing an event, and not so low that passing traffic, etc., might cause spurious events to be recorded.

The portable instruments tend to be more versatile, and offer more practical uses than the remotely installed instruments, since they can be moved to any location, and can collect both high and low level data. This is of lesser importance when monitoring airblast, because of the difficulty in applying predictive techniques to airblast data. For airblast monitoring, portable instruments can be moved to any position inside or at the the perimeter of the permit area, and to any outside point of concern or complaint site.

All instruments used for airblast monitoring should be equipped with windscreens over the microphones, which should be placed in an area not masked by trees or buildings, at least 5 ft. to the side of any structure, and 3 ft. to 5 ft. above the ground.

When monitoring both ground motion and airblast at a structure, it is desirable to employ an instrument that records the ground motion and airblast as full waveform time histories. In case of excessive adverse impacts, or persistent complaints, the airblast and ground motion time histories may then be compared in order to identify the major cause of any problem. At boundary limits, for compliance monitoring [Section 816.67(b)(2)] or for verification, a peak reading airblast monitor is adequate.

When employing consultants to carry out airblast monitoring programs, be particularly careful that the consultant is, in fact, a specialist in blasting vibrations. It might seem that this caution is unnecessary, however one proposed local airblast ordinance was recently based on the study of a professional engineer who was not only apparently unaware of the differences between 'sound' and 'airblast', but did not seem to fully understand the difference between a steady state and an impulsive event. He attempted to use the noise study parameters such as dBA, Leq, and d', and also based his conclusions on measurements made of only two events at a single location in mountainous terrain! Should any prospective consultant prepare to monitor a shot, displaying any of the above tendencies, or using a "sound level decibel meter", it should be taken as an immediate warning that he is not sufficiently experienced or competent in blast vibration monitoring and control. Be very careful when selecting a consultant.

GROUND MOTION MONITORING

Whenever ground motion needs to be recorded for whatever reason, by the mine operator, independent consultant or regulatory authority, the actual placement of the instrumentation is the primary consideration. Adequate time should be allowed for the proper set-up of the instrumentation at the chosen location, before the detonation of the blast. Hurried instrument set-up can lead to imperfect orientation and sensor-to-ground coupling, and will often result in less than adequate results.

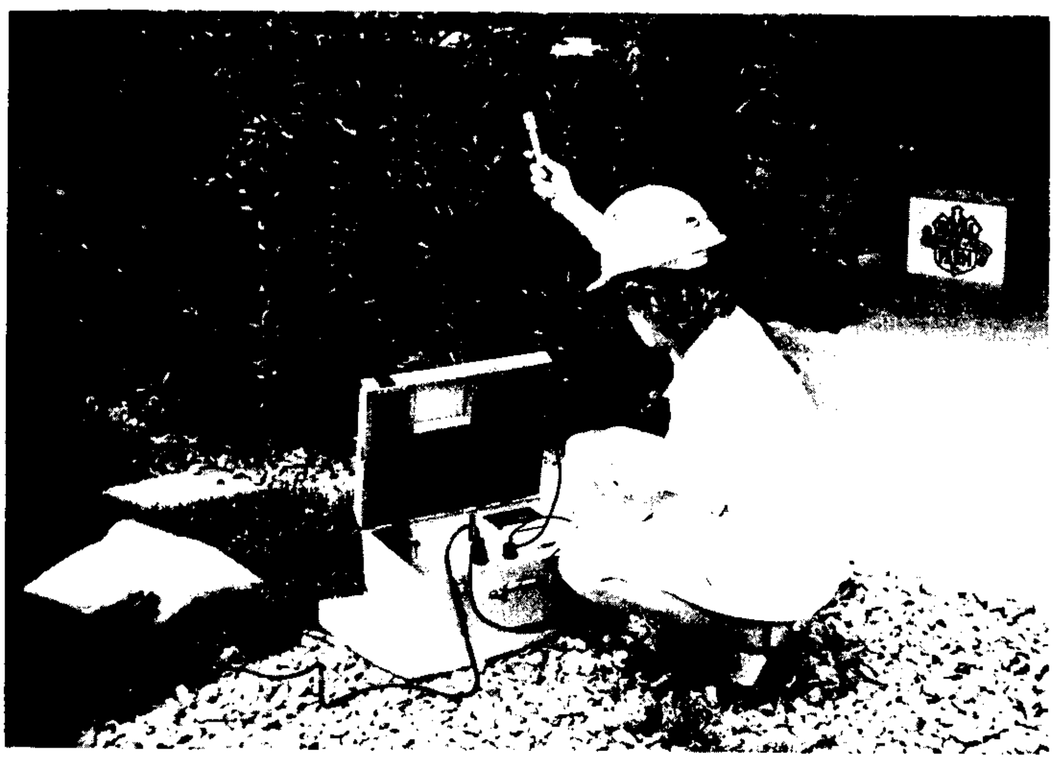


Figure 20.
Monitoring ground motion and air blast.

The first consideration in terms of instrument placement is the actual location of the ground motion sensor, or transducers. This placement has to be decided both in terms of distance from the blast site, and, at a structure, in terms of the transducer placement relative to the structure.

Distance from the blast is not always a matter of choice. If it is necessary to monitor ground motion at the particular structure then obviously distance from the blast is dictated by the distance that structure is from the blast. If this limitation does not apply, then it is essential to remember that the most useful data will be collected at as widely different scaled distances as possible. The distance to the blast decision, if open, will be dependent upon recent monitoring history: if large scaled distance data is already available, then the aim should be to collect data at small scaled distances. Attempt, as far as possible, to collect data at as low a scaled distance as is safe and prudent, and at as high a scaled distance as is measurable. In between these extremes, it is desirable to have as even a distribution of data as possible. Whenever the choice of distance is open to the operator, the temptation to set-up the instrument in the same, easy, convenient spot where it was last time must be avoided. Vary the data, and the extra effort will be found to be well worth while when the need to predict vibration arises, as sooner or later it surely will.

The second consideration in terms of instrument location concerns the local placement of the transducers with reference to the structure itself, and the actual connection of the transducer head to the ground, or "coupling".

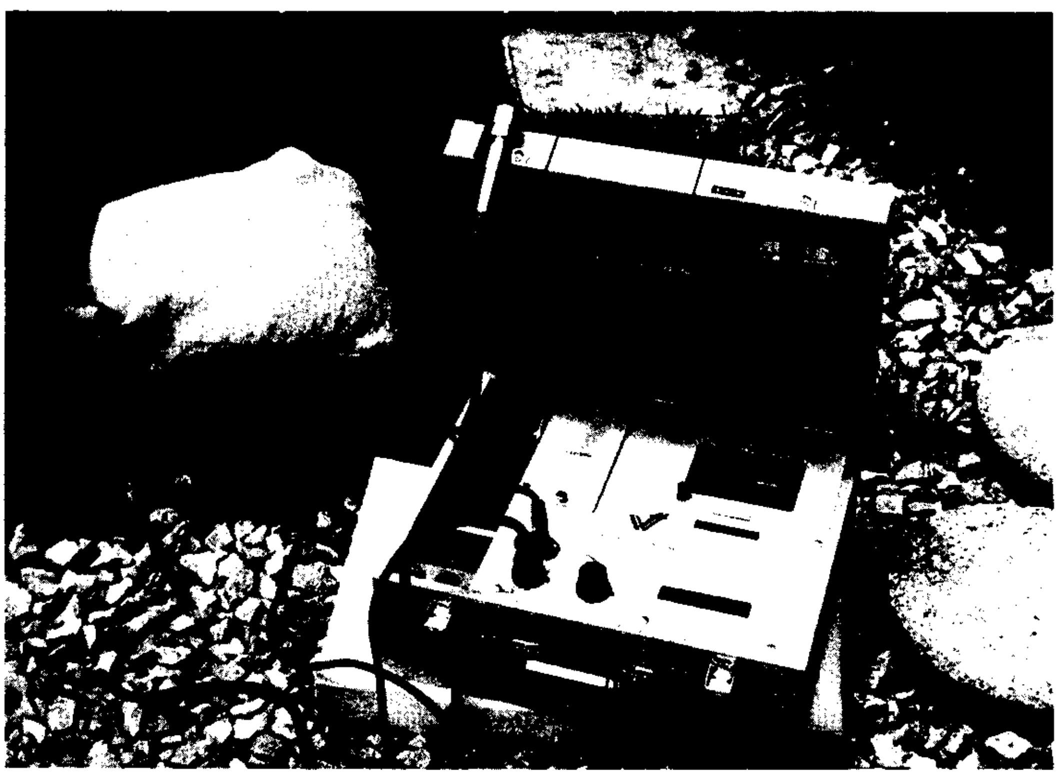


Figure 21.
Instrument placement.

The placement of the transducer head should be outside any building or structure of concern, since the vibration limits are for effects at the point of entry to a structure. Locations which are also influenced by an incidental or background vibration - heavy rotating machinery, compressors, etc. - should be avoided. It is quite common for a householder to request that the instrument be placed inside a house, or on a window sill. In most cases these requests are made because this location is where the vibration was most strongly experienced. This request should always be resisted, explaining that any location other than outside the structure will not measure incoming ground motion, but only structure response, and that structure response was carefully considered when the OSMRE drafted the ground motion regulations. There is no need to be reluctant to admit that structure response is sometimes higher than the incoming ground motion. If the insistence on an internal structural measurement is so great that this request is conceded to, make absolutely certain that in these cases any internal monitoring is backed up by a proper external ground motion measurement as well.

Sometimes, however, particularly in the case of constant recording remotely installed instruments, it is desirable to place the instrument inside the structure simply in terms of weather protection. A common placement for the transducer in such cases will be an internal mounting on a concrete foundation or basement wall. In such circumstances it is important to place the transducers at approximately the outside surface level on an outside concrete basement wall or foundation, preferably at the corner intersection that is closest to the blast. A partition wall is not suitable because it has a tendency to resonate.

Normally, the transducers should be placed on a compacted earth or soil surface, as close to the foundation of the structure as possible, correctly leveled and oriented towards the blast, following the instrument manufacturer's instructions. This requirement is so that the planes of measurement are kept in a proper and consistent relationship, i.e. that the longitudinal (or radial) component is indeed measured longitudinally, and not transversely, to the blast. Some transducer heads have a small bubble level to indicate a level position, on other instruments a satisfactory calibration cannot be achieved if the heads are not in a sufficiently level position. Exact, precise leveling is not necessary.

Coupling is the single most important transducer head placement consideration. If the manufacturer provides a ground coupling spike to be attached to the underside of the transducer head, <u>it should always be used</u> providing the ground is at least soft enough for the spike to be pushed fully into place. In addition to this, if at all possible, and even when the vibration levels are expected to be quite low, it is always good practice to cover the transducer unit with a loosely filled 15 - 25 lbs. sandbag. Burial of the transducer unit is sometimes advocated, with soil compacted around the transducer head to a depth of at least 2/3 the transducer height, but digging a hole will sometimes disturb the soil on which the transducer is placed to such an extent that in effect the transducer is placed on loose uncompacted soil, and the ground to transducer coupling will suffer accordingly.

Figure 22.
Sandbag and spike transducer head
to achieve good coupling.

When high vibrations are expected, special considerations apply. Obviously, the risks of ground to transducer decoupling are increased, and careful thought must be given to ensuring continuing and complete coupling. Some transducer heads are provided with a through hole: if a threaded stud is fired or cemented into an exposed rock outcrop, the transducer head can be securely bolted down, using the storage mounting bolt supplied with the instrument. Other methods of secure transducer placement in such circumstances include cementing or gluing in place. A very suitable and cheap material for this is plaster of paris. This is not only very quick, but the bond can easily be broken at the conclusion of operations, and the excess plaster remaining can easily be removed from the transducer head with no risk of damage to the instrument. Care must also be taken to protect the body of the instrument from direct exposure to airblast and vibration. It should be placed on a soft foam rubber pad, and shielded from direct exposure to the incoming airblast shock wave.

Occasionally, in special circumstances, transducers have to be mounted sacrificially with no possibility of retrieval following the operation. In such circumstances, it is wise not only to check the cost of such a sacrificial transducer, but also to remember that when being fitted with a new transducer head, in all probability the instrument will have to be recalibrated. Such recalibration costs can be quite significant, sometimes several hundred dollars.

Loose or smooth surface transducer placement should be avoided without some sort of coupling support under all circumstances, even when the velocities expected will be low, but when acceleration levels are expected to be over .2 g's.

If any decoupling or slippage occurs the results of any measurements will be gravely in error. If peak reading instruments are used, this will be hard to detect, although with time history recordings, such decoupling is normally immediately apparent, visible in the waveform "signature".

Once these basics are complied with, the choices are much as were open to the operator for airblast monitoring.

- Peak only vs. entire time history.
- Permanently or semi-permanently installed vs. portable.
- Monitoring by consultants.

The first option, however, is restricted, because of the frequency responsive ground motion limitations in the OSMRE regulations. Apart from secondary, or backup peak readings taken in conjunction with a second time history recording instrument, the only times 'peak only' reading instruments are acceptable are: (a) when the instruments are used to monitor velocities at points within the permit area, when compliance is not an issue anyway, and (b) when compliance is being sought under the requirements of Sections 816.67(d)(2)(i) and 816.67(d)(3)(ii).

Similar considerations apply to the decision to use permanently installed "constant-recording" instruments, versus portable operator attended or set-up instruments, as in the case of airblast monitors. An important consideration in the case of ground motion, however, is the existence of instruments which may be set-up in the field either in a portable or in a "constant-recording" mode. Instruments of this type can offer increased versatility. They provide the advantages of variable and varying data collection in the portable mode, as well as the convenience of use in a 24 hour per day monitoring situation, in a fixed location for week or a month, or for whatever period might be necessary to deal with any particular complaint or concern situation.

The arguments discussed under AIRBLAST MONITORING concerning the relative advantages and disadvantages of seismically triggered instruments are also identical. Only the operator can decide just what type of instrument is best suited to his needs. Very often the use of instruments on a rental basis is the most convenient answer to this problem; either because of the ease of switching to another instrument without a significant capital expenditure, or, as a prelude to purchase, a rental period to serve as a practical field trial.

Since many of the instruments available today offer a full airblast recording capability along with seismic monitoring, all the airblast considerations already discussed are pertinent in a seismic, or ground motion recording mode.

Consultants should still be chosen with a great deal of care. Ground motion is far better understood among the non-specialist consulting engineers than is airblast, but nevertheless, if the decision is taken to retain a consultant for monitoring, it is wise to make certain that he is experienced and known in the field.

The result is a form of bar graph, on which are recorded deflections from a baseline occurring for each blast or other vibration-producing event. By knowing the sensitivity of the recorder, and the rate of movement of the chart paper, both the peak recorded values and their times of occurrence can be determined over periods as long as 30 to 60 days. Even if a peak recorder is able to continue to operate unattended for such long periods, it is advisable to remove the records on a much shorter time cycle, in order that excessive vibrations are recorded in a timely fashion, and do not go uncorrected.

The major advantage of the peak recorder is the low cost and simplicity of the equipment, as well as the fact that it can operate with minimal attention and manpower expense.

Its major disadvantage is that no frequency information is recorded. Because the potential for structural damage is frequency-related, the data obtained is of limited value, except in cases where the vibration levels are so low that damage will not occur regardless of frequency. Compliance with OSMRE regulations would only be fully satisfied if the peak particle velocity was lower than 0.2 inches per second, or if compliance was being sought under Section 816.67(d)(2)(i) or (3)(ii).

Another problem with peak recording instruments is that non-blast events, such as bumping the geophone or slamming a nearby door, cannot be distinguished from blast vibrations even though the differences in their waveform 'signatures' are quite distinct. Therefore, because of these possible interpretative doubts, the value of these records in damage determination and litigation situations is somewhat limited. In general, the application of these instruments should be limited to situations where the vibration levels are certain to be low and the potential for complaints is also minimal. Peak recorders restrict the choice of the operator in terms of vibration level compliance options.

Although peak recorders produce only one trace, containing only peak information, they nevertheless have to record ground motion in all three planes. The ground motion sensors, therefore, still must incorporate three mutually perpendicular geophones. Although the trace will not identify in which plane the peak occurred, OSMRE regulations will be satisfied since the requirement is for maximum velocity in any plane. See Note 3/ to Section 816.67(d)(2)(i). Some of these instruments provide a vector sum peak reading. This is also acceptable, since the vector sum velocity will always exceed or equal the maximum any plane velocity.

THE WAVEFORM RECORDER

These instruments are the most commonly-used blast monitors. They are distinguished by their capability of producing a particle velocity analog of a ground vibration waveform. Some have features which allow more sophisticated and accurate computerized techniques for damage prediction. However, the minimum requirements for waveform instruments are as follows:

1. Three mutually perpendicular geophones which can be oriented to sense vibration in the vertical direction, along a horizontal line between the blast and the geophone (longitudinal or radial), and along a horizontal line at right angles to the other two (transverse). This assures that all components of ground vibration are sensed by one or more of the geophones and can be added vectorally if necessary. This also complies with OSMRE regulations, Note 1/ to Section 816-67(d)(2)(i).

2. The capability of responding to ground vibration frequencies of 4 Hz or lower, at ±3dB, or down to 5 Hz at ±1 dB. This assures that all vibration energy within the 4 to 12 Hz fundamental frequency range of residential structures will be accurately recorded.

3. The ability to reproduce all frequencies up to at least 50 Hz. This enables the accurate determination of both the amount of energy in the fundamental frequency range of residential structures as well as that energy causing resonance of individual walls and other structural elements. This also permits compliance with the Blasting Level Chart option, Section 816.67(d)(4)(i).

4. The capability of recording peak ground vibration levels at frequencies up to 200 Hz to conform with USBM recommendations.

5. A dynamic response range from at least a minimum of .05 inch per second to a maximum of no less than 2.0 inches per second.

6. An internally-generated calibration signal which tests the entire system, including the geophones, for accurate operation. The instrument's response to this calibration signal should be displayed on the record as proof of proper operation and to allow for corrections when necessary. Failing this, the instrument should have recent (within one year) factory calibration records, showing calibration traceable to the National Bureau of Standards.

Instrumentation

7. Unless a separate airblast recorder is used, there must be a capability of recording peak airblast with an upper frequency limit of at least 200 Hz to comply with Section 816.67(b)(2)(ii). The low frequency limits may vary in accordance with the requirements set forth in Section 816.67(b)(1)(i).

The output of the blast monitor should be in the form of a particle velocity time history record of the event. This time history may be generated on-the-spot by an onboard printer or may be put on photographic film, tape, diskette or other memory device and analyzed at a later time. There are always advantages and disadvantages with any system that need to be considered.

To assure proper analysis and maximize credibility, legal experts recommend and some regulatory agencies (but not OSMRE) require that independent vibration consultants perform the analyses of vibration records. Regardless of whether a record is on film, magnetic tape or a field-generated strip chart, all records should be analyzed, or at least verified for validity, by a qualified person not connected with the mining operator or explosive contractor.

A recent innovation in blast monitoring instrumentation is the microprocessor-based unit. This provides a field record by sampling the vibration wave at a high rate, storing the sampled values in its memory and then printing out these values as strings of points on a strip chart so that an approximation of the original waveform is drawn. At the same time the peak values sampled from the geophones and microphone are printed out with the waveform to provide a peak particle velocity and airblast analysis of the blast.

This "instant" analysis has the advantage of timeliness, and provides a certain amount of information regarding the frequency content of the vibration wave. The expense of monitoring is also reduced, as long as the operator is not inclined or required to obtain a formal verification of the results by an independent vibration analyst.

If evidence of conformance to a single-number particle velocity criterion is the only requirement, this method may be satisfactory. Low velocities, or velocities measured in accordance with Section 816.67(d)(2)(i) or (3)(ii) will conform in these terms.

Vibration waves are, in general, a complex mixture of many frequencies. Visual examination of a vibration printout is usually a rather crude method of determining which frequencies are important from the standpoint of structural damage potential. For instance, a particle velocity peak may be the result of the addition of several frequencies having different significance in terms of structural response. On the other hand, important frequencies from the standpoint of structural response may not be apparent by visual examination, because they are masked by other less significant frequencies.

The implication of this is that conformance to the OSMRE frequency dependent criteria shown in Figure 12, page 24, (Fig. 1, OSMRE Regulations) can most conveniently and accurately be accomplished by a computer technique which separates the vibration wave into its component frequencies. There are several methods which can be used to accomplish this. It is only through the use of such a technique, however, that a valid correlation between amplitudes and frequencies can be plotted directly against the variable particle velocity limits shown on this graph.

The seismic information gathered by present-day digital onboard waveform printing instruments cannot be supported in this way. After the stored digital points are used to plot the particle velocity waveform, the digital information is discarded and no further analyses can be performed, except for example by "hand-digitizing" the waveform for further separate analysis by computer. In such instances, however, hand digitizing error can be additive to normal instrument error: great care must be exercised with these techniques.

Future instrumentation of this type will no doubt result in more relevant and sophisticated analyses than are currently available. Such capability is, in fact, within the realm of present-day technology. When it becomes implemented into this type of instrument, it will provide the blaster or his consultants with a far better insight into the damage potential of ground vibration than is currently available using onboard printing instruments.

Another point to consider is that the need for seismic instrumentation goes far beyond the basic control of ground vibration levels and the fulfillment of OSMRE regulatory requirements. Civil lawsuits are a common result of blasting operations, and the vibration data gathered by the mine operator can be crucial in determining the extent to which he may be judged liable.

When property damage lawsuits do occur, it is imperative that the mine operator be able to produce seismic evidence that is accurate, complete and provable. Opportunities for falsification, suppression or other tampering of seismic evidence must be kept to a minimum by whatever means are practical. Evidence demonstrating proof of non-damage is of paramount value: in most states, lawsuits only have to prove a causatory connection between the blast and the damage. Negligence does not have to be proven: it is usually not an issue.

Instrumentation

Experience of lawyers, vibration consultants and other experts in the area of blast damage liability has shown that certain data-gathering procedures and instrumentation requirements are important in establishing the credibility of seismic and airblast evidence in litigation proceedings, as follows:

1. Proof of Calibration: Most instruments have a built-in calibration test circuit which checks the continuity and accuracy of all data channels. The response of each channel to the calibration input signal is printed out, either automatically or on command of the operator. The calibration test response pulse should be included with every blast record to indicate the accuracy of the recording system.

All seismic instruments should also be shake-table calibrated by a competent vibration testing facility at least once a year, and a current certification of calibration should be provided, traceable to the National Bureau of Standards.

2. Third-Party Analysis: Blast recordings which provide an on-the-spot analysis, or are analyzed by the mine operator, may be subject to questions regarding their admissibility in civil actions. This question of credibility may, at times, become a very important issue because of the potential for a conflict of interest on the part of the mine operator.

This is the reason why it is desirable that the analyses of blast records be made by an independent third-party expert. Besides minimizing the potential for conflict of interest, an expert analyst is able to identify problems in recording procedures, instrument operation, and blast design that may otherwise go unnoticed.

Third-party expert analysis is a key facet of any blast monitoring and structural damage protection program. Even when "instant analysis" type instruments are used, review of these records by an independent expert is highly advisable to assure the validity of the results and to identify possible problems.

3. Witnesses: Whenever a blast is recorded, an individual other than a representative of the mining company should, if possible, be present to observe the operation of the instrument. Ideally, the witness should be familiar with the operation of a blast monitor such as a regulatory inspector. However, a homeowner, tenant or other interested party might also be asked to observe any blast recording to at least substantiate the fact that a recording was made. Sometimes local government officials or employees can be prevailed upon to undertake this function, as can members of the local media.

SUMMARY OF BLAST VIBRATION MONITOR SPECIFICATIONS AND CAPABILITIES.

Company; Model; Type;	Sensitivity Ranges: Seismic: ips, (Air: dB)	Frequency Response: Seismic: Hz (Air: Hz)	Manual, Seismic or Air Trigger	Recording Format:	Country of Origin:	OSM "Option No." Suitability:	Record/Recall Capabilities:	Availability of Frequency Information:	Power Requirements:	Wgt. (lbs)	Fig. No.
Dallas Instruments: BR-2-3 / VS-3 PEAK;	0-2, 0-4, (NA)	1-200 (NA)	M	Bar graph on 30 day strip chart.	U.S.A.	1 and 3	Max component continuous recording. Vector sum optional.	None.	3 x 6V Lantern battery. Ext.DC power plug.	25	23
Dallas Instruments: BT-4 WAVEFORM;	0-4 (100-137)	1-200 (5-200) (2-200 Opt.)	M	Magnetic Tape Cassette[1]. Peak-hold meter readout.	U.S.A.	1 and 3, also 4 if computer analysed.	3 component seismic and air data stored on tape[2].	Visual estimate thru seismogram. Computer analysis[2].	3 x 6v Lantern	28	24
Dallas Instruments: SM-4 WAVEFORM;	0-4 (100-137)	1-200 (5-200) (2-200 Opt.)	M S(Opt)	Magnetic Tape Cassette[1]. LCD display of peak readings.	U.S.A.	1 and 3, also 4 if computer analysed.	3 component seismic and air data stored on tape[2].	Visual estimate thru seismogram. Computer analysis[2].	12V rechargeable battery. Ext. DC power.	28	N/A
Dallas Instruments: ST-4 WAVEFORM;	0-4 (100-137)	1-200 (5-200) (2-200 Opt.)	M,S	Magnetic Tape Cassette[1]. LCD display and BCD printout of summary data.	U.S.A.	1 and 3, also 4 if computer analysed.	3 component seismic, air and summary data stored on tape[2].	Visual estimate thru seismogram. Computer analysis[2].	12v rechargeable battery. Ext. DC power.	30	25
Dallas Instruments: ST-4D WAVEFORM;	0-4 (100-137)	1-200 (5-200) (2-200 Opt.)	M,S,A	Magnetic Tape Cassette[1]. LCD display of summary data.	U.S.A.	1 and 3, also 4 if computer analysed.	3 component seismic, air and summary data stored on tape2. 94 event summ. data printed out with peripheral equipment.	Visual estimate thru seismogram. Computer analysis[2].	12v rechargeable battery. Ext. DC power.	30	26
Digital Vibration: TELEBLAST WAVEFORM;	0-2 (100-140)	5-200 (6-200)	S,A	Portable printer and terminal for summary data. Remote based computer/plotter for waveform data.	U.S.A.	1,3 and 4	3 component seismic and air. Dial-up phone link central computer/printer /disc data storage.	Direct data interface with computer for time-history, Fourier & response analysis.	110V AC with standby 24V battery.	42	27(a) 27(b) 27(c)
Instantel DS-377 WAVEFORM;	0-8 (100-140)	2-250 (2-250)	M[4],S,A	Waveform and summary by pen printer/plotter. Computer type keyboard.	CANADA	1 & 3, +4 if manually digitized into computer.	3 component seismic, air and summary data on paper printout. 50 event auto. recording. Continuous recorder optional.	Visual estimate thru seismogram. Manual digitizing req. for computer analysis.	6V rechargeable battery. Ext.DC power plug. 2nd 6V battery req. for opt. heater.	42	N/A
Philip R. Berger & Associates: SSU II WAVEFORM;	0-2 (Max 145)	5-200 (6-200)	M	Waveform by direct photo print chart recorder. LED readout of seismic peaks.	U.S.A.	1,3 and 4	3 component seismic and air on paper printout.	Visual estimate thru seismogram. Manual digitizing required for computer analysis	12V rechargeable battery.	26	28
Philip R. Berger & Associates: SSU 1000D WAVEFORM;	0-4 (110-140)	2-256 (2-256)	S,A	Waveform and summary data by onboard dot-matrix thermal printer. Typewriter style keyboard panel.	CANADA	1 and 3, also 4 if computer analysed.	3 component seismic, air and summary data on paper printout. 40 event automatic recording per paper	Visual estimate thru seismogram. Manual digitizing req. for computer analysis.	6V rechargeable battery. External DC power.	29	29
Slope Indicator S-2 / S-3[5] WAVEFORM:	0-20 (Max 162) (5 gain settings)	5-150 (1-350)	M	Waveform by onboard direct photo print 7-channel chart recorder.	U.S.A.	1,3 and 4	Two 3 component seismic channels and optional air on paper printout.	Visual estimate thru seismogram. Manual digitizing required for computer analysis	12V rechargeable battery.	50	30 & 31
Slope Indicator S-6 WAVEFORM:	0-30 (Max 168)	5-200 (5-400)	S,A	Wave form and summary data by onboard strip chart. LCD display of summary data. RS232C interface for external printer or computer.	U.S.A.	1,3 and 4	Two 3 component seismic channels & optional air. Three storage/recall modes.	Spectral energy recorded within 11 frequency bands.(13 for air) Direct computer interface for analysis of waveform data.	12V rechargeable battery.	26	32
Sprengnether Instruments: VS-1200 WAVEFORM:	0-5[3] (Opt.)	2-200 (Opt.)	M	Waveform by onboard photo print chart recorder.	U.S.A.	1 & 3, +4 if manually digitized into computer.	3 component seismic on paper printout.	Visual estimate thru seismogram. Manual digitizing required for computer analysis	12V rechargeable battery.	52.5	33
Sprengnether Instruments: VS-1600 WAVEFORM:	0-6.4 (Max. 140)	4-200 (2-200)	M,S	Waveform by onboard photo print chart recorder. LCD display of summary data	U.S.A.	1 & 3, +4 if manually digitized into computer.	3 component seismic on paper printout.	Visual estimate thru seismogram. Manual digitizing required for computer analysis	12V rechargeable battery.	30	34
Vibra-Tech/ VME: Vibra-Tape® GMS-4 Series 2000 WAVEFORM:	0-4 (100-140)	2-200 (5-250)	M	Magnetic tape cassette[1]. Peak-hold meter peak data capture. Voice on sound channel capability.	U.S.A.	1,3 and 4	3 component seismic and air data stored on magnetic tape[2].	Visual estimate thru seismogram. Direct computer analysis available.	2 x 6V Lantern batteries.	28	35
Vibra-Tech/ VME: Vibra-Tape® Series 5000 EVERLERT WAVEFORM;	0-4 (100-140)	2-200 (5-500)	S,A	Digital grade magnetic tape cassette. LCD readout of summary data. Tape readback facility.	U.S.A.	1,3 and 4	3 component seismic, air and summary data stored on tape. Field recall of all summary tape data including time & date.	Visual estimate thru seismogram. Direct interface with computer for complete analysis.	2 x 6V rechargeable Lantern batteries. Ext. DC power supply & charger unit.	30	36
Vibra-Tech/ VME: SEISTECTOR PEAK;	0-.5,1 or 2 Factory set (N/A)	5-200 (N/A)	M	Bar graph on 30 day strip chart, with hourly timing marks.	U.S.A.	1 and 3	Max. component (or vector sum) continuous recording.	None.	110VAC with 8 hr standby battery (supplied) or 12V ext. battery	10	37
Vibra-Tech/ VME: VR Model F WAVEFORM;	0-4 (Max 140)	5-200 (5-200)	M	Waveform by onboard photo print chart recorder.	U.S.A.	1 & 3, +4 if manually digitized into computer.	3 component seismic and air on paper printout.	Visual estimate thru seismogram. Manual digitizing required for computer analysis	12V rechargeable battery.	35	38
Vibra-Tech/ VME: VR Model G WAVEFORM:	0-4 (NA)	5-200 (NA)	M	Waveform by onboard photo print chart recorder.	U.S.A.	1 & 3, +4 if manually digitized into computer.	3 component seismic on paper printout.	Visual estimate thru seismogram. Manual digitizing required for computer analysis	12v rechargeable battery.	35	39

Notes:
1 30 minute tape normally recommended by manufacturer.
2 Time history, frequency spectrum, building response and computer analyses per OSM and USBM frequency responsive criteria available through consultants.
3 Selectable velocity, displacement and acceleration output. Six gain settings.
4 7 second recording period in manual mode.
5 Model S-3 has selectable velocity, displacement and acceleration outputs.

Table 4.

Table 4, on page 61, is a summary of most of the instruments found in the field today including general descriptions of their important features, advantages and limitations. It is important to emphasize that these descriptions are, of necessity, very general. Many subtle differences exist in the design details of similar type instruments. Some of these differences may be insignificant for one application but vitally important in another. Engineering changes are also made regularly within given models to improve their operation and take advantage of technology advances. This is particularly true for the newer microprocessor-based models where software changes can be made which change their capabilities without any change in hardware.

It is therefore recommended that whenever instrument capabilities are in question, the manufacturer or the appropriate consultant should be contacted to obtain information regarding a specific instrument and the suitability of its intended application.

The illustrations contained in the following pages show almost all of the instruments described in Table 4 on page 61, and are referenced in the last column of that table.

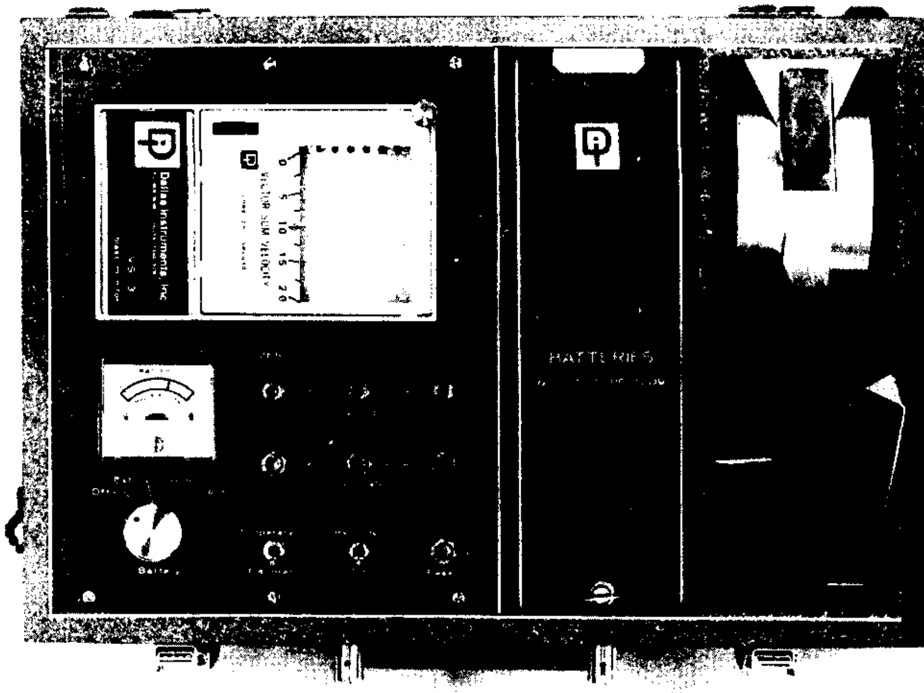


Figure 23.
Dallas Instruments VS-3.

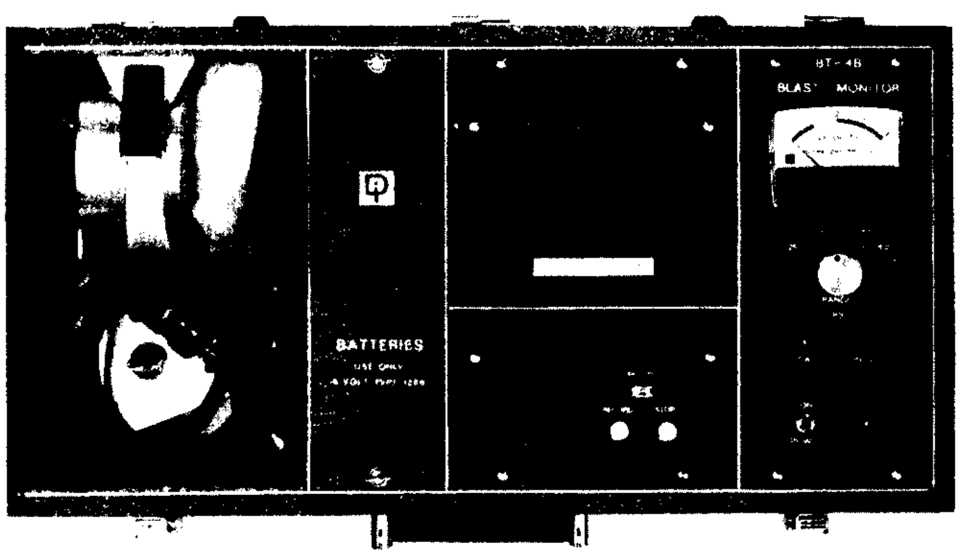
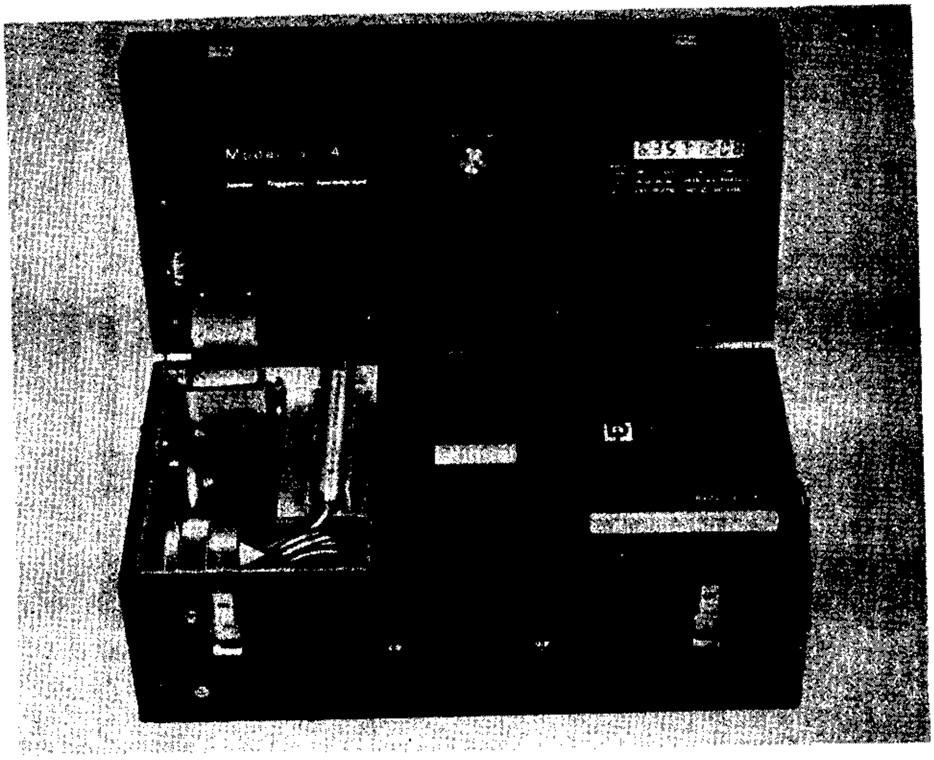


Figure 24.
Dallas Instruments BT4-B.



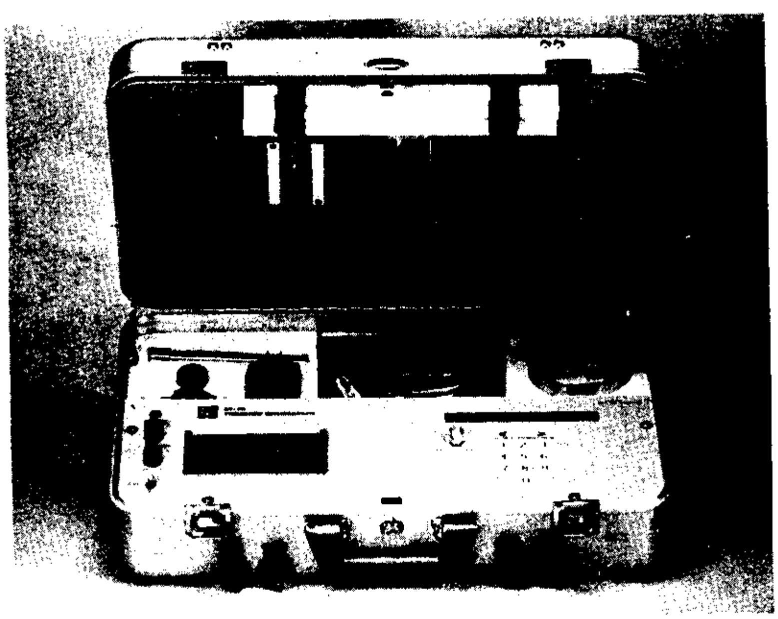


Figure 26.
Dallas Instruments ST-4D.

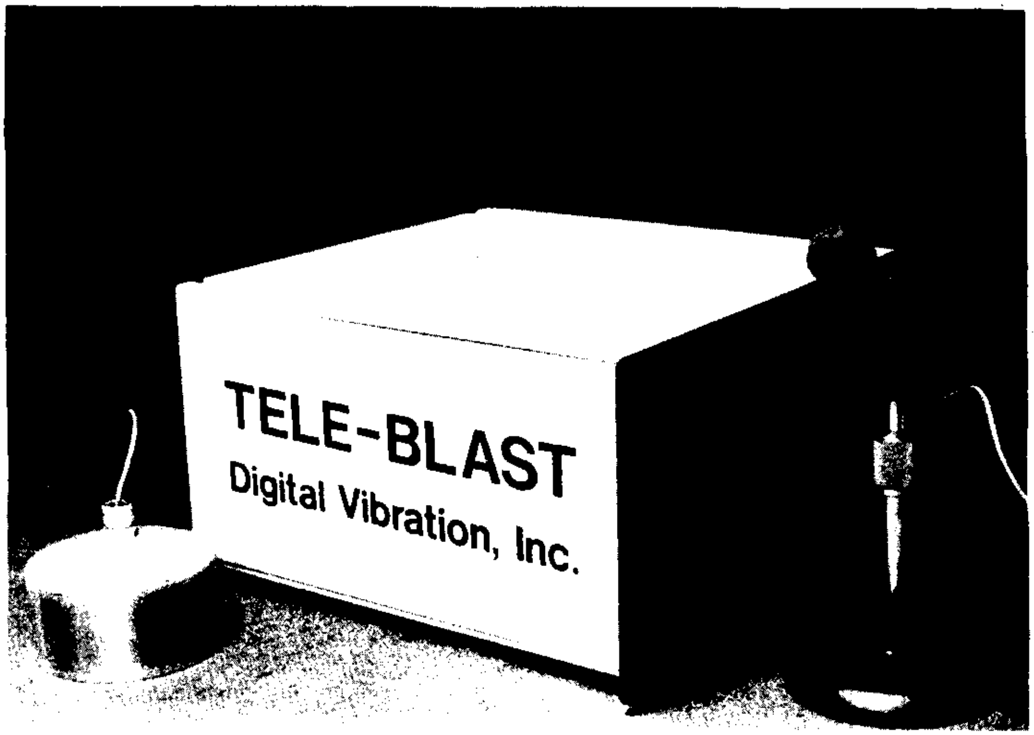


Figure 27(a).
Digital Vibration Teleblast.

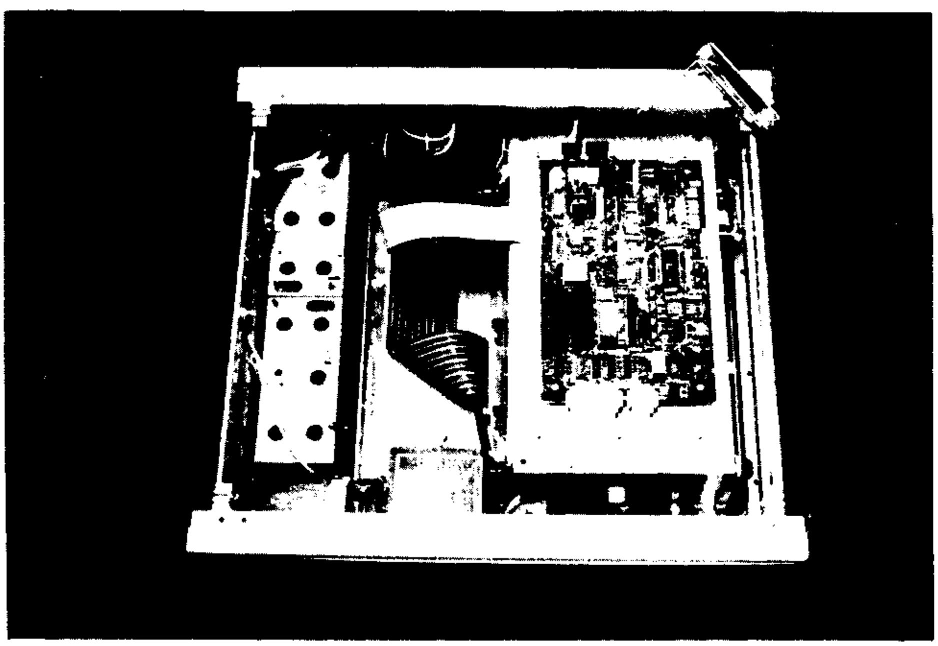


Figure 27(b).
Digital Vibration Teleblast.

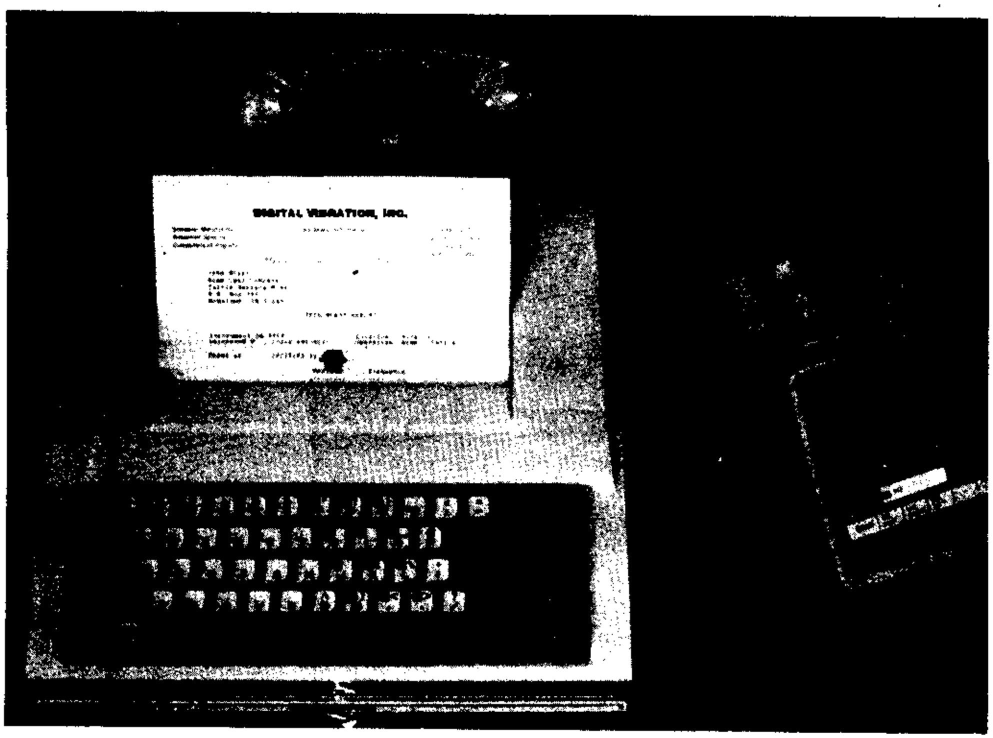


Figure 27(c).
Digital Vibration Teleblast.

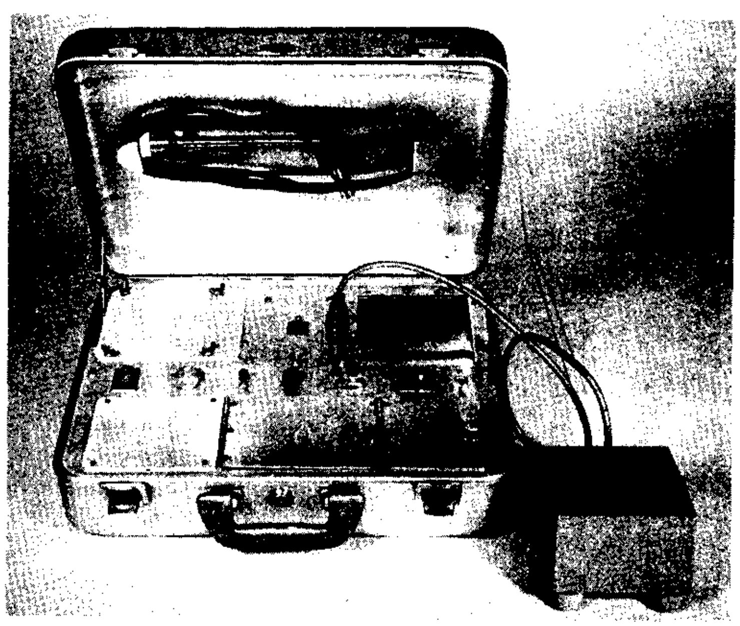


Figure 28.
Philip R. Berger & Associates SSU II.

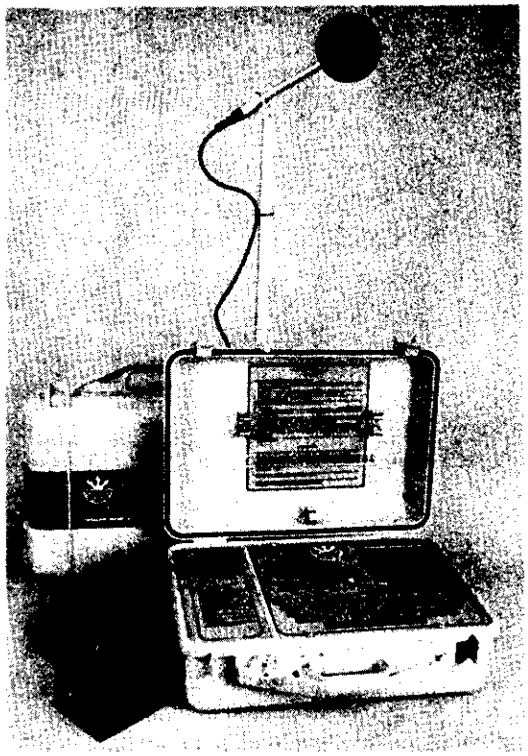


Figure 29.
Philip R. Berger & Associates SSU 1000D.

Figure 30.
Slope Indicator S-2.

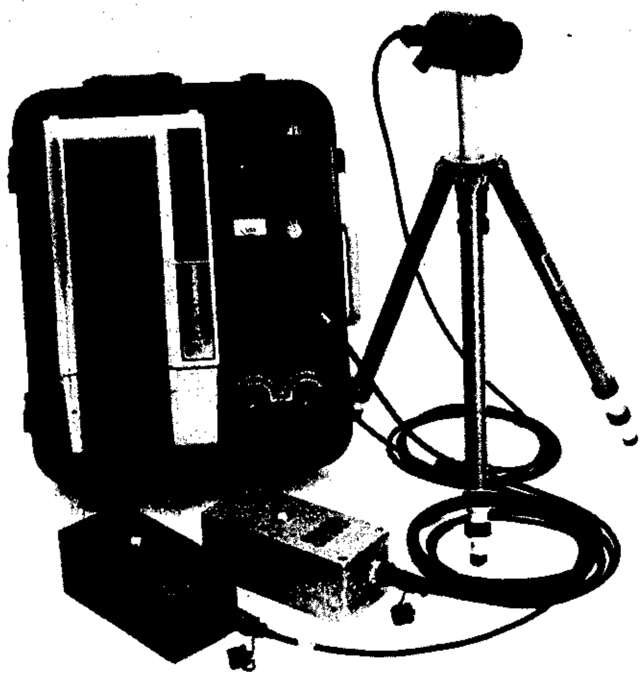


Figure 31.
Slope Indicator S-3.

Figure 32.
Slope Indicator S-6.

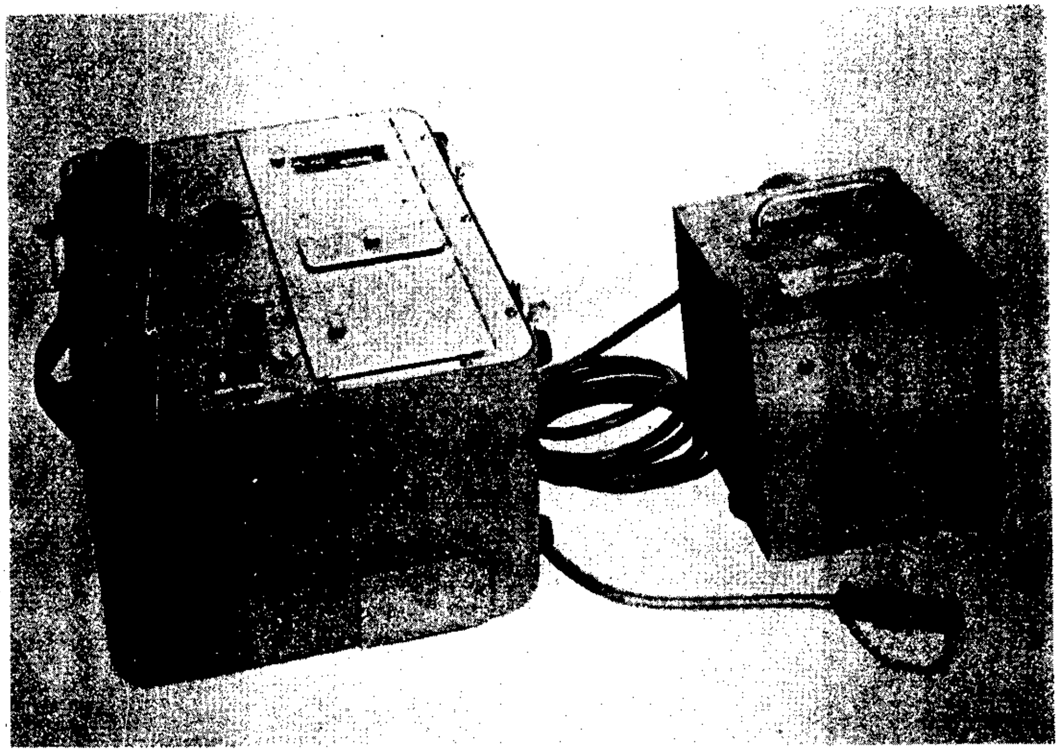


Figure 33.
Sprengnether Instruments VS-1200.

Figure 34.
Sprengnether Instruments VS-1600.

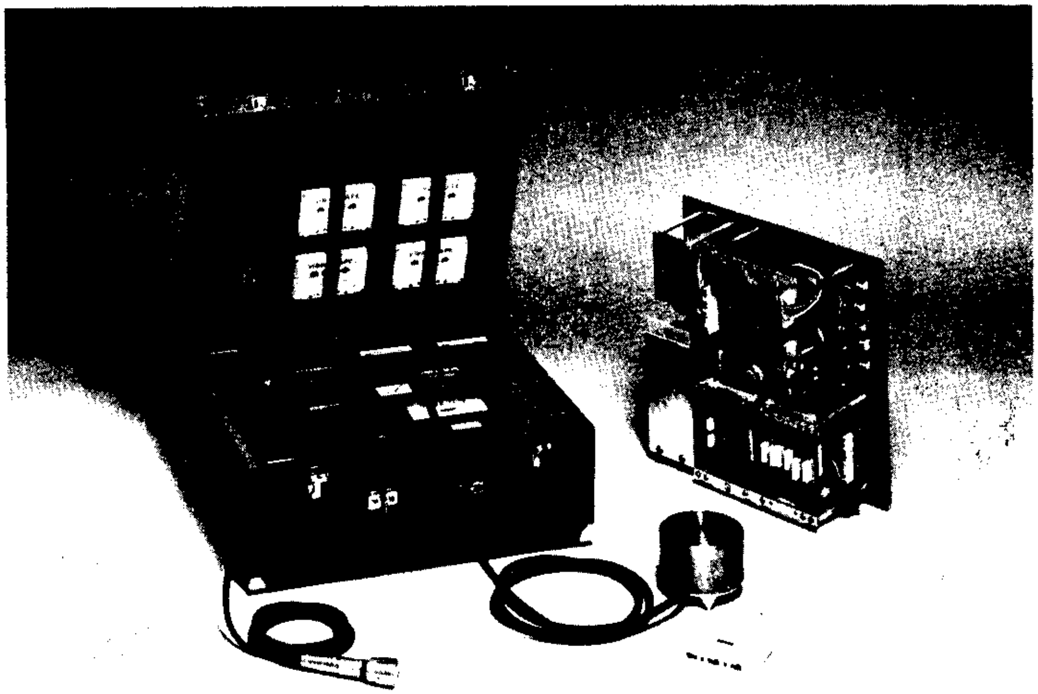


Figure 35.
Vibra-Tech/VME Vibra-Tape® GMS-4.

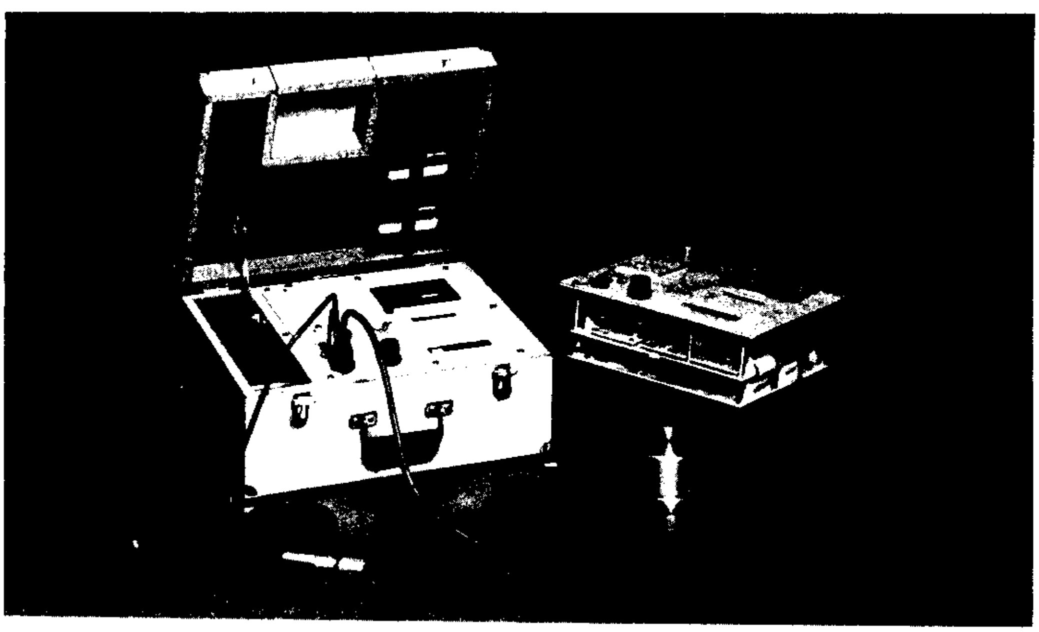


Figure 36.
Vibra-Tech/VME Vibra-Tape® Series 5000.

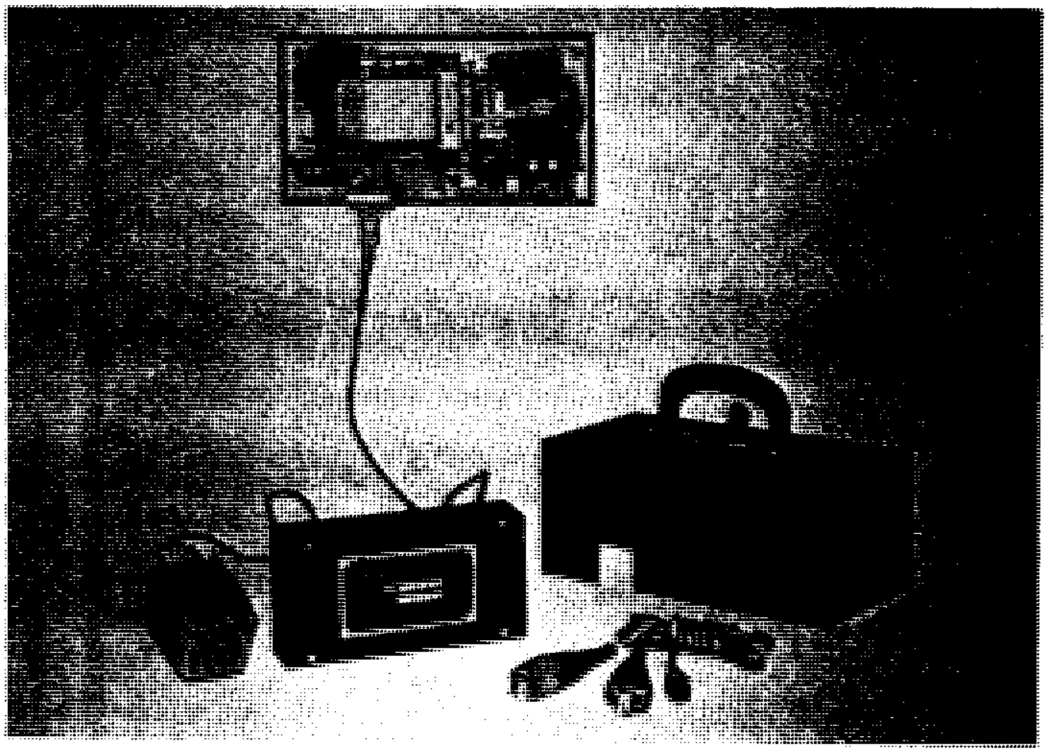


Figure 37.
Vibra-Tech/VME Seistector®.

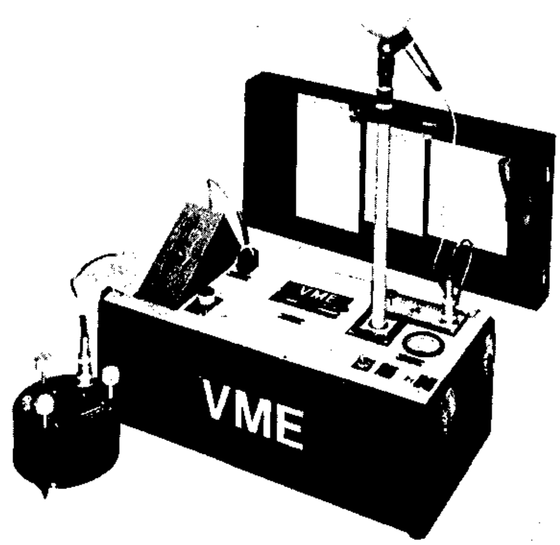


Figure 38.
Vibra-Tech/VME VR Model 'F'.

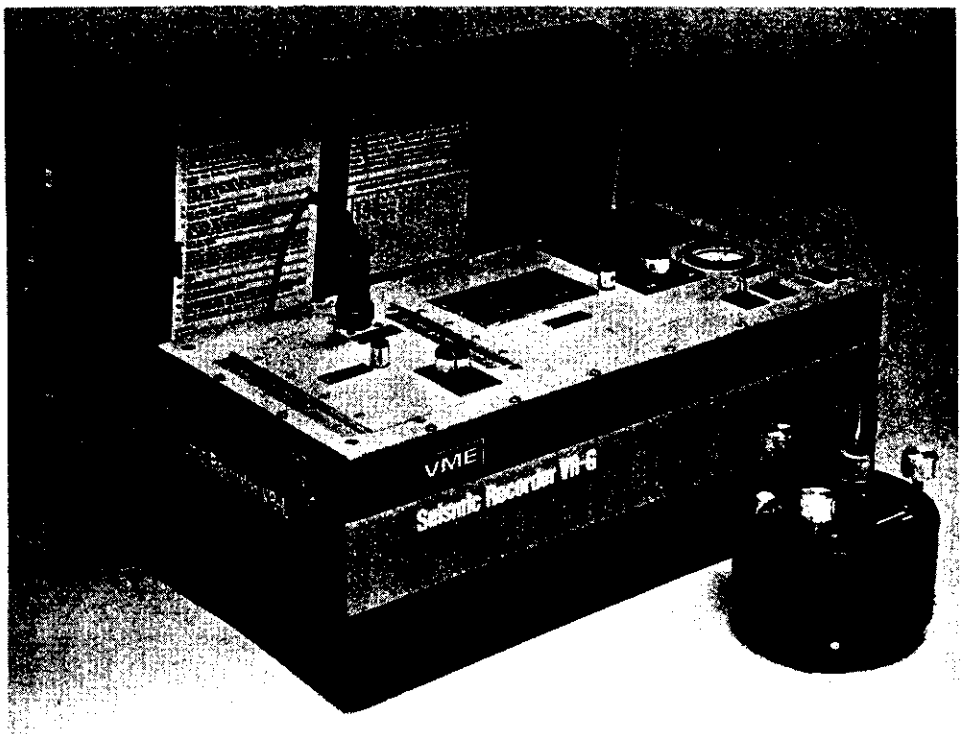


Figure 39.
Vibra-Tech/VME VR Model 'G'.

CHAPTER 9

COMPLIANCE OPTIONS AVAILABLE TO THE OPERATOR

GROUND MOTION

The OSMRE regulations allow the operator to choose from four optional methods to control ground vibration:

1. Section 816.67(d)(2)(i) Maximum Peak Particle Velocity: Providing that each shot is monitored, and a seismograph record is provided, this first option is DISTANCE related, and requires merely that:

(a) From 0-300 ft. distance: max. PV = 1.25"/sec.

(b) From 301-5000 ft. distance: max. PV = 1.00"/sec.

(c) From 5001 ft. to beyond: max. PV = 0.75"/sec.

2. Section 816.67(d)(3)(i) Scaled Distance Equation: This method does not require that blasts be monitored, but it relates a permissible MINIMUM SCALED DISTANCE (Ds) to DISTANCE, and requires adherence to these as follows:

(a) From 0-300 ft. distance: min. Ds = 50

(b) From 301-5000 ft. distance: min. Ds = 55

(c) From 5001 ft. to beyond: min. Ds = 65

3. Section 816.67(d)(3)(ii) Modified Scaled Distance: This is not distance related, but is based upon the collection of site specific data, and the statistical analysis of this data, using the predictive methods covered in the "PREDICTION AND CONTROL METHODS" Chapter in this manual.

4. Section 816.67(d)(4)(i) and (ii) Blasting Level Chart: This is the most precise, and also the most unrestrictive option available to the operator. It requires the monitoring, recording and analysis techniques that provide complete frequency information, since the vibration limitations imposed, up to 2.0 inches per second, are frequency related.

Discussing these options in order, and referring to them throughout this manual, and in Table 4. (Page 61, Instrumentation) as Options 1, 2, 3 or 4, it is possible to detail them, together with their advantages and disadvantages.

Available Compliance Options

OPTION 1: MAXIMUM PEAK PARTICLE VELOCITY

This option, and option 2, Scaled Distance equation, might at first sight appear to be illogical in that the closer a structure is to the blast, the higher the velocity (or lower the scaled distance) that is allowed. Common sense would seem to advise the reverse. However, because of the fact that higher frequencies are less damaging to structures than lower frequencies, and that the closer to a blast, the higher are the frequencies, this regulation is, in fact, perfectly reasonable.

Option 1 is the simpler of the options that require monitoring on a permanent basis, and will permit the second highest vibration levels. It only requires peak effect monitoring, without any frequency reference, and all of the measurements can be made at, or outside, the permit area, usually at the particular structure of concern.

OPTION 1 ADVANTAGES:

- "Peak only" reading instruments are acceptable.
- No frequency information is needed.
- Little operator expense involvement.
- Maximum PV of up to 1.25"/sec. are allowed at short distances (when higher maximums may be more useful).
- Generally permits shorter distances and/or higher charges per delay than the scaled distance options.

OPTION 1 DISADVANTAGES:

- Every shot must be monitored.
- Does not permit the maximum velocities allowed under option 4.
- Each shot might have to be monitored in two or more separate locations, dependent on distances.
- If peak only reading instruments are used, will not assist in identifying potential blasting problems.

OPTION 2: SCALED DISTANCE EQUATION

Option 2 is the only non-site specific option, and therefore, being based on generalized data collected over the whole of the U.S., it is the most restrictive, although it is undoubtedly the simplest of all the ground motion compliance options. It requires only that the distance from the shot to the point or structure of interest is related to the maximum charge weight per delay, as a square root scaled distance, thus:

$$Ds = D/W^{\frac{1}{2}}$$

Where D = the distance, in feet; and

W = the maximum charge weight per 8 ms. delay period, in lbs.

Since this formula can be rewritten:

$$W = (D/Ds)^2$$

then, substituting Ds according to the regulation and the actual distance, it becomes easy to calculate a maximum charge weight per delay allowable at that distance.

The following table shows allowable maximum charge weights per delay under this regulation, at various distances:

DISTANCE-FT	MINIMUM Ds	MAX. CHARGE WT/DELAY, LBS.
100	50	4.0
300	50	36.0
310	55	31.8
330	55	36.0
500	55	82.6
1,000	55	330.6
2,000	55	1,322.3
5,000	55	8,264.5
5,100	65	6,156.2
5,900	65	8,239.1
6,000	65	8,520.7
10,000	65	23,668.6

The above figures naturally show some anomalies at the regulatory Ds change distances of 301 ft. and 5001 ft.; however, since it is most likely that when this option is adopted the conditions will not be critical, and the distances will probably be over 2 or 3 thousand feet, this is of no great consequence. The regulation itself is written to allow blasting at distances less than 300 ft., with no minimum distance stipulated, provided that the requirements of Section 761.11(e) are complied with (mainly that the owner of any occupied dwelling within a radius of 300 feet has provided a written waiver consenting to such operations). Although the regulation allows a minimum scaled distance at these short distances, the charge weights per delay permissible are usually too small to permit any practical production mine blasting. Really effective control of blast vibrations at short distances is far better left to Option 4, the Blasting Level Chart.

Whenever blasting is carried out, and instruments are not used to record the vibrations, it becomes increasingly important for the operator to take all possible steps to reduce ground motion and airblast. It is therefore imperative, when monitoring is not being done, that utmost care be taken to minimize vibrations. (See pages 33, 35, 40, 41, 42, 43 and 44, and Figures 14 to 17 in this manual).

OPTION 2 ADVANTAGES:

- No monitoring is required.
- Simple scaled distance control only.
- Minimum cost.

OPTION 2 DISADVANTAGES:

- The most restrictive of all the options.
- Not related to actual velocities: least effective protection in the event of complaint situations.
- Impractical at short distances.
- Only effective under non-critical distance/charge weight relationships.
- Will not assist in identifying potential blasting problems.

OPTION 3: MODIFIED SCALED DISTANCE

This, and option 4, are far more effective under more critical conditions than is option 2. Both options 1 and 3 rely on site specific measurements, but option 3 translates these measurements into a statistically predictive scaled distance, with a confidence level of 95%. This avoids the need for regular monitoring of every shot, although it must be stated here that once a modified scaled distance is authorized by the regulatory authority, it must be subject to periodic review and renewal. This is discussed specifically later in this chapter.

The methods by which the site specific vibration measurements are converted into a scaled distance formula are detailed in this manual's Chapter 10 on PREDICTION AND CONTROL METHODS. Computer and calculator programs are provided in Appendix 'A' (pages 135 to 165) for those who wish to process their own data, although it is recommended that this type of predictive work be done, if possible, by experienced blast vibration consultants, because of the many pitfalls that can beset the inexperienced venturer in this field.

For the purposes of this section, however, these methods will be described only in outline, with emphasis being placed on compliance, and their relative advantages and disadvantages to the operator, as has already been done for options 1 and 2.

The first point that must be firmly established regarding option 3 concerns the amount of data that is needed to assure authorization of a modified scaled distance. The answer to this is complex:

It must be realized that when statistical sources are consulted for the answer to this question, they only provide the information that the 'n' value, the number of data pairs required for a valid statistical analysis, should be "large". For the purposes of this manual's guidance, 30 or more data pairs will be considered a suitably large 'n' value. Therefore, the following qualified answer is offered:

<u>If the data is good; a minimum of 30 data pairs are acceptable.</u>

Obviously, the real qualifier is the goodness of the data. There is a simple solution to the problem, however, based on the fact that the prediction methods used work very well provided the data used is collected sensibly, accurately, and consistently. Therefore, when embarking on a program to collect data to form the basis for an authorized modified scaled distance, these basic rules must be adhered to:

1. Remember that the data pairs needed are peak particle velocity versus scaled distance. So as to properly utilize options, scaled distance data must be collected as distance in feet with maximum pounds of explosive per delay period.

2. When collecting scaled distance data, do so on the basis of:

(a) Measured distances (NOT GUESSED).

(b) Measured explosive weights (NOT GUESSED).

Careful explanation to the blasting crew of the methods and purposes will help here. Do not simply rely on the figures written on the reports; check personally to see that they are factual.

3. When recording blast vibration data, do so on the basis of the maximum peak particle velocity that occurred in any plane, for each shot. One instrument recording is required for each velocity data point. If more data is required, per blast, then more instruments must be used.

4. Separately identifiable data should be recorded for coal shots and overburden shots. Sometimes the characteristics will be close enough between the two to permit a common scaled distance formula, but frequently this is not the case. Other similar significant geological variations will also require separation of the data in this way.

5. Collect data at as wide a range of scaled distances as possible: see remarks on this subject on Pages 48 and 49, and also on Page 133, Appendix 'A'. In any event, data MUST be collected at at least as low a scaled distance as it is hoped will be authorized and preferably lower than this.

6. Collect data at an even spread of scaled distances between the highest and the lowest.

7. Collect data consistently, using the same instrumentation, recording it in the same geological formations, and avoiding interposed features that might cause higher or lower than normal results, such as streams, hills or excavated areas, etc. (See Figure 56. in Appendix 'A', page 131.)

8. Exclude data where it is known that conditions were not normal. For example, if it were known that propagation occurred, or if there were misfires, etc.

Once these rules are observed, it will be found that the collected data is good. If problems persist in terms of getting good data, then it is time to start looking for problems that may not be known to exist. The fact is that careful monitoring can lead to a more efficient and trouble-free operation, and this should be encouragement and motivation in itself.

The final results of these calculations, together with the supporting data, must be submitted to the regulatory authority for approval. Authorization for a modified scaled distance will be forthcoming, as long as the data is good; as long as there are sufficient data pairs, and if the calculations are correct.

Once a modified scaled distance has been authorized, it must be reviewed and renewed from time to time. This is one point that is not covered by the regulations, although it is of great importance. Particularly on the larger surface mines, the area in which today's operations are taking place may be a significant distance from the area in which last year's operations took place. The geographic and geological differences can well mean that the site specific formula for last year is no longer specific to this year's site.

It is recommended that modified scaled distances be reviewed, updated if necessary, and re-authorized at least annually. The data required for this would be as for any initial modified scaled distance application.

Although this third option would seem to require a great deal of effort and application, it provides a site specific velocity attenuation formula that can be of inestimable value in the event of complaints from unexpected quarters - and sometimes great distances. Where it might have been thought quite unnecessary to monitor, a complaint situation frequently will cause the operator to wish he had had the foresight to have taken some readings at the complaint site. The existence of a site specific attenuation formula will offset this omission to a very large degree, since instead of a site specific measurement, a calculation based on the attenuation formula can often establish clearly that a damage situation was not possible.

OPTION 3 ADVANTAGES:

- No regular monitoring required.
- "Peak only" instruments acceptable.
- No frequency information needed.
- Maximum of 1.25 inches per second allowed at short distances, based on the site specific rather than general data.
- Provides reasonable protection in complaint situations.

OPTION 3 DISADVANTAGES:

- Does not offer minimum restriction to operations.
- Must be reviewed and renewed at least annually.
- Offers less complaint or lawsuit protection than frequency responsive methods.

OPTION 4: BLASTING LEVEL CHART

This is undoubtedly the least restrictive of the four available options and although it may appear to be the most costly, it can offer the most in side benefits and cost savings to the operator.

Every shot must be monitored, and a frequency responsive instrument must be used. As has already been discussed, however, the advantages that accrue from the use of such instruments should not pose too great an additional burden in this respect. In addition to this, the latest computer analysis techniques provide an easy to understand (and easy to verify) graphic representation, so that compliance can be checked at a glance. Figure 40, which shows a typical computer analysis printout for a Vibra-Tech GMS-4 Analog blasting seismograph, illustrates this point. For each of the three planes, the computer will print out a particle velocity versus frequency graph, very similar to the Figure 1. (OSMRE Regulations) Blasting Level Chart, complete with the frequency responsive maximum velocity indication on it. As long as the velocity versus frequency graph lies below the maximum velocity limit line, it is a clear indication that the vibrations are in compliance.

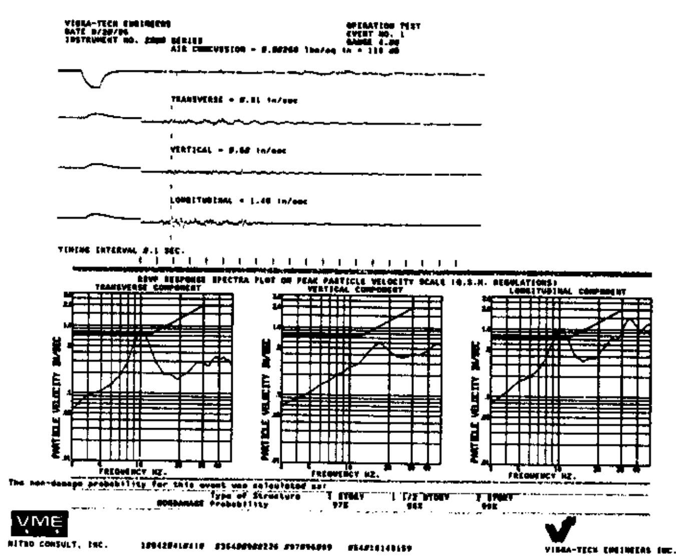


Figure 40.
Typical computer printout of blast vibration waveforms.

The data gathered when this option is exercised are also the most useful, both in terms of protection from damage claims and lawsuits, and also for predictive purposes. Since the frequency at which the maximum vibrations occur is known, in all three planes, the possible effects will also be much easier to demonstrate and to predict.

When more critical conditions are approached, at closer distances, the predominant frequencies of the ground motion tend to get higher. Therefore, in general, it will be found that the closer the blasting is to a structure, the higher are the permitted velocities. When at or over 30 Hz, 2 inches per second is permitted. When this higher velocity limitation is coupled to the fact that any predictive exercises are based on current site specific information, it will be realized how far less restrictive to the operator this last option is.

It should be noted at this point that frequency determination is not a simple procedure, as careful scrutiny of Figure 40 will confirm. If reference is made to the preamble to the Rules and Regulations (Federal Register, Vol 48, No.46, Tuesday March 8, 1983) on page 9802 OSMRE states:

"Commenters requested clarification as to what was required to evaluate blast vibration frequency. They wanted to know whether visual inspection of seismographic records was adequate or whether electronic analysis of frequency would be required. Under Section 816.67(d)(4), which requires regulatory authority approval of the method of analysis of the predominant frequency contained in the blasting records, visual inspection may be adequate if traces are distinct and only a few frequencies are contained in the wave-form. However seismographic consultants have found that various waves with multiple frequencies typically are contained in the blasting record. In those cases, electronic analysis is necessary to separate the wave traces and analyze each intensity and frequency. OSM does not intend to mandate electronic analysis; rather the determination of what type of analysis is appropriate should be made by the regulatory authority .... Except when the criteria of Section 816.67(d)(4) are used, the final rule leaves frequency analysis to the discretion of the regulatory authority. OSM recognizes its value as an indicator of vibration damage probability, but also recognizes the complexity and expense in its application ...."

This fourth option can be most usefully employed if it is used in conjunction with the predictive techniques described in Chapter 10, PREDICTION AND CONTROL METHODS. Quite apart from the benefits that these techniques provide when unexpected or unusual complaint situations arise, they are the only methods that permit blasts to be detonated, knowing in advance that velocity limitations will not be exceeded. Once that capability is properly understood, and these techniques are utilized to the full, the guesswork and uncertainty in blast design can be virtually eliminated, certainly as far as vibrations are concerned. A distance will be known, and it will be known from previous records just what the predominant frequencies will be. The maximum permissible peak particle velocity can then be found, and, using the regression techniques mentioned, a safe scaled distance, relative not only to those exact site characteristics, but to that particular shot, can be established. Once that is known, the blaster can be told his maximum permissible charge weight per delay. He is then totally free to design his shot, with an absolute minimum of restrictions. He can always, therefore, work to the optimum conditions. The shot is monitored, for confirmation of compliance, and the new data is added to the old data and run through the predictive techniques once more, so that the next shot will again be based on totally up-to-date and current predictive information.

Notwithstanding the apparent - and actual - effort involved with this option, it will be found that this effort will be amply repaid in terms of minimum restrictions, optimum blasting efficiency, maximum protection and complete compliance.

OPTION 4 ADVANTAGES:

- Least restrictive: permits highest velocities, maximum loadings and shortest distances.
- Permits greatest freedom in blast design.
- Greater freedom in blast design can result in lower drilling costs, optimum drilling and blasting efficiency.
- Maximum liability protection.
- Complete compliance.
- Greatest total savings.
- Employs OSMRE encouraged use of response spectra (see page 81).
- Provides OSMRE approved evidence of regulatory compliance and damage potential.

OPTION 4 DISADVANTAGES:

- Every shot must be monitored.
- The instrument must be frequency responsive.
- Highest cost, neglecting possible savings offset.
- Needs careful and thorough implementation.

When considering any of the above options, only the operator can really decide what is best for his own particular situation. The simplest and cheapest options tend to be more restrictive, and do not offer the side benefits that frequently moderate the apparent cost and effort involved in the less restrictive options.

CHAPTER 10

PREDICTION AND CONTROL METHODS

When any monitoring methods are carried out that collect vibration data against distance and explosive weight data, it is possible to analyze that data in such a way that it becomes an indicator of the vibration effects for future blasting and not merely a record of past events. Since it is obviously better to know in advance whether blast vibrations will be excessive, rather than merely to record them hopefully, these prediction and control methods are presented as the core of efficient, safe and responsible blasting operations.

Whether the purpose is to develop a modified scaled distance, for compliance under Section 816.67(d)(3)(ii), or to ensure that the limits imposed under Section 816.67(d)(2)(i) or (4)(i) and (ii) will not be exceeded, or simply to control critical blasting effects, the basic technique is the same. The underlying principle is that each mine or blasting site is different from another, and that minor differences exist within each site, such as the geology and techniques of blasting, hole size and depth, drill and blast pattern, and blast hole loads, in addition to the location and distance to structures of concern.

Scaled Distance (Ds) is a fundamental relationship between distance in feet from the blast to the recording instrument or point of concern and the maximum explosive charge weight in pounds per 8 ms delay period. It is expressed as the distance, feet, divided by the square root of the charge weight per delay, pounds, thus:

$$Ds = D/W^{\frac{1}{2}}$$

When statistical analysis techniques are applied to blast vibration data pairs, peak particle velocity against the scaled distance at which that velocity was measured, a site specific velocity attenuation formula can be developed. The technique is known as a least squares regression analysis, and the velocity attenuation formula takes the form:

$$V = H(Ds)^{-\beta}$$

where V = peak particle velocity, inches/second,

H = particle velocity ('y' axis) intercept at Ds = 1.0,

Ds = scaled distance, and

β = curve slope (decay exponent - always negative).

The variable values H and β are constants for each particular site: each regression analysis carried out on the PV/Ds data pairs will determine a specific value for each of these terms. Generally speaking, H can vary between perhaps as low as 20 or 30 to as high as 1000 or more. The slope β will normally be no lower than -1.1 or -1.2 or so, and will sometimes be as high as -2.2 or -2.4. The often quoted and referenced general use velocity attenuation formula published in the DuPont Blasters' Handbook (16th Edition, p. 426) is:

$$V = 160(Ds)^{-1.6}$$

This is of course, very conservative, and is not site specific, being derived from data obtained over a very wide range of geographically and geologically different blasting sites. Conservative as this formula is, it is not as conservative or limiting as the dictates of Section 816.67(d)(2)(i) and (3)(i). The following table relates the two and indicates the need for proper site specific velocity determination and prediction techniques, whenever the local conditions are anything more than completely non-critical:

DISTANCE	Ds(3)(i)	PV(2)(i) (Permitted)	PV (DuPONT FORMULA) (Probable max. actual)
0-300 ft.	50	1.25"/sec.	0.30"/sec.
301-5000 ft.	55	1.00"/sec.	0.26"/sec.
5000 ft. +	65	0.75"/sec.	0.20"/sec.

It is this type of restriction - essential when no monitoring is to take place - that can be circumvented and replaced by site specific, factual and far less restrictive compliance options when prediction and control methods are fully exploited.

A plot of particle velocity versus scaled distance is a complex curved line on linear graph paper. To show this relationship as a straight line, and to compress a wide range of values onto a single sheet, the plot is made on logarithmic co-ordinates. The slope of the curve, being negative, shows that as the scaled distance increases, the peak particle velocity decreases.

The data pairs, carefully and systematically collected as discussed in Chapter 9 (Compliance Options: Modified Scaled

Distance) are input to the regression analysis calculation, which can be performed on any small computer, or even a programmable calculator. The resultant equation is for a geometric curve in the form:

$$y = ax^b$$

or:

$$\log y = \log a + b \log x$$

which shows a linear relationship between both x and y in terms of logarithms. Drawn on 3 cycle "log-log" paper, the curve can be represented as a straight line, and can accommodate a scaled distance range of 1 to 1000, and a peak particle velocity range of 0.01 to 10.0 inches per second.

The statistical confidence level adjustment procedures described in this manual are those commonly used throughout the blast vibration control profession, and therefore:

- If the data collection methods recommended in this manual are closely adhered to,

- If at least thirty data pairs are obtained (preferably in excess of thirty),

- If the data is properly distributed,

- If appropriate distinction is made between coal, overburden, and presplit blasts, and

- If the topography between the blast and seismograph is sensibly considered,

then the regulatory limits will not be exceeded.

To assure the reliability of the equation, the attenuation formula must be adjusted statistically to a 95% confidence level, and the 'goodness of fit' or coefficient of determination (r^2) of the data should be no less than 0.7. The standard deviation, used in establishing the confidence level, should be as close as possible to zero. In actual fact, it is not likely under practical conditions that the standard deviation will be less than 0.2, but it should not be much greater than 0.5 or so.

If the standard deviation becomes too large, the H variable of the attenuation formula will increase to the point that the 95% confidence level will only be attainable at large scaled distances, approaching the non-site specific scaled distances allowable under Section 816.67(d)(3)(i). In order to derive maximum benefit, in this respect, the standard deviation should be reasonably low.

When the goodness of fit is too low, below 0.7 or so, this is an indication that there is some problem or inconsistency in the data. When this occurs, a review of the data and test procedures is advisable, and a series of additional tests must be carried out.

Even if the data is not usable in a predictive manner, or if a modified scaled distance cannot be established in this way, the results are still of great value. This might be the situation where the analysis, while not providing the looked for results, has nevertheless made a clear statement that must not be ignored:

> "THE DATA IS NOT GOOD! Look for a problem that may exist in the data collection, recording methods, drilling and blasting procedures, or blast design."

While this may not actually identify the problem, it has alerted the operator to the fact that a problem exists. If he then reviews his records and procedures, if he then looks for the difficulty, the chances are very good that some sort of inconsistency or deviation will be found. Once identified in this way, corrective action can be taken, and a problem will be resolved which otherwise would have gone unrecognized.

The resultant information should never be regarded as final, as long as some ongoing vibration monitoring is to take place. As soon as new data becomes available, it may be added to the old, and the attenuation formula, and supporting information, constantly updated for optimum reliability.

PREDICTIVE DATA: USAGE FOR MODIFIED Ds

Once a minimum of 30 data pairs has been collected and the regression analysis performed, by the mine operator or by an independent consultant, the analysis and supporting data must be submitted to the appropriate regulatory authority. On approval, a specific attenuation formula will be authorized for use at the location where the data was collected.

In order to determine exactly what modified scaled distance must be used in planning the blast, the distance to the structure of interest or concern must be known, so that the appropriate maximum peak particle velocity may be arrived at under Section 816.67(d)(2)(i).

Let it be supposed, for example, that the distance in question was 1385 ft. From the regulation, at this distance the maximum allowable peak particle velocity would be:

1.00 inch/second.

Let it also be supposed that the site specific attenuation formula derived from the collected data was:

$$V = 149.2(Ds)^{-1.51}$$

Since this formula can be rewritten:

$$Ds = (149.2/V)^{1/1.51}$$

substituting the allowable 1.0 inch per second velocity for V will give, at the distance of 1385 ft., a modified scaled distance of:

27.5

NOTE: This scaled distance is for this shot only, in terms of a maximum of 1 inch per second velocity, at the structure of interest, at a distance of 1385 ft. It has to be recalculated for every other shot, dependent on the distance to the structure of interest, which in turn dictates the allowable velocity.

Since the scaled distance formula:

$$Ds = D/W^{\frac{1}{2}}$$

can also be rewritten as:

$$W = (D/Ds)^2$$

again, using this example's values for substitution, it can therefore be calculated that using the modified scaled distance, the maximum explosive charge weight per delay that could be detonated at 1385 ft. distance would be:

2536 lbs.

Using the Section 816.67(d)(3)(i) scaled distance regulation alone, at 1385 ft., a scaled distance of 55 would have been permitted, allowing a maximum explosive charge weight per delay of only:

634 lbs.

Obviously, this is only a hypothetical example, but the attenuation formula selected for the argument is not in any sense extraordinary. The increase in allowable charge weight, according to circumstances - and care in collecting the base data - may be less, even considerably less, but it could even be more. What this example does try to illustrate, however, is that the potential to remove, or lighten the restrictive load on the operator is a very significant one. From being restricted to no more than 634 lbs. per delay to over 2500 lbs. per delay does not mean that the operator has to shoot 2500 lbs. per delay, but it does mean that he can design his blast up to that charge weight per delay in terms of drilling costs, optimum breakage, and blasting efficiency, rather than simply to comply with the regulations.

Appendix 'A', between pages 135 and 149, contains a complete computer program, written in BASIC, that will run on the majority of small IBM and IBM compatible computers, from the IBM PCjr., through the PC to the AT. This program is designed specifically to embody all the requirements of the OSMRE regulations, and to permit all the necessary steps to be taken to prepare a modified scaled distance application to be submitted to the regulatory authority. Also included in this appendix is a reference to a general use regression analysis program that will permit complete and versatile control of blasting vibrations, without specific reference to the OSMRE regulations, and a similar, but simpler, hand calculator program, on pages 164 and 165.

PREDICTIVE DATA: USAGE FOR COMPLIANCE WITH SECTION 816.67(d)(4)(i) - BLASTING LEVEL CHART - AND FOR GENERAL AND CRITICAL PREDICTIVE PURPOSES.

For compliance, the collected data must be frequency responsive, as already discussed. While the basic techniques are the same, the maximum permissible velocity is based on the predominant frequency of the vibration, rather than on the distance alone.

Let it be assumed that the data collection and regression analysis provided the same attenuation formula as in the previous example. Taking a critical, close distance example, for comparison purposes, let the distance from the blast to the structure be 275 ft., permitting a maximum of 1.25 inches per second under (2)(i), and let it be assumed that in the case of the frequency responsive data, the predominant frequencies at this short distance were in excess of 30 Hz, allowing a maximum velocity under (4)(i) of 2 inches per second.

Under (2)(i) the modified scaled distance would become 23.7, allowing a maximum explosive charge weight per delay of:

134.6 lbs., at 275 ft.

If compliance were sought under (4)(i), while the operator must still monitor every shot for both velocity and frequency, the scaled distance that could be used to design the next shot would be:

$$Ds = (149.2/2)^{1/1.51} = 17.4$$

allowing, at 275 ft. distance:

$$W = (275/17.4)^2 = 250 \text{ lbs. per delay.}$$

Again, using precisely the same attenuation formula, and only changing the method of compliance - the operator's option - it is clear that nearly twice the weight of explosive can be detonated! At close distances, under critical conditions, this kind of difference can truly be said to provide relief from restriction. Efficient and practical blasting methods can indeed be used at close distances, and the operator will remain in complete compliance with OSMRE regulations. Care must be exercised, however: though these calculations are based on the statistical probability of NOT exceeding 2.0 inches per second at a confidence level of 95%, and it is therefore likely that recorded vibrations will be well below this level, nevertheless IF a velocity in excess of 2.0 inches per second were recorded then the operator would be subject to a violation.

Quite apart from considerations of compliance or not, these methods offer complete control and protection when:

- Blasting has to be carried out within short distances of sensitive structures well within the permit area.

- Allegations of blasting damage are made at locations, distant or close, where no vibration measurements had been made. The maximum possible effects can be accurately calculated.

These methods and applications are discussed fully in Appendix 'A', together with examples of typical calculations.

CHAPTER 11

FREQUENCY CONSIDERATIONS

It is important to be able to determine the frequency content of a ground vibration signal because the response of structures to blasting vibration is dependent on both particle velocity and frequency. Frequency is the number of oscillations per second that the ground surface vibrates as the seismic energy created by a blast passes by a particular location. Frequency is usually expressed in units called Hertz (Hz). (1 Hz = 1 oscillation per second.)

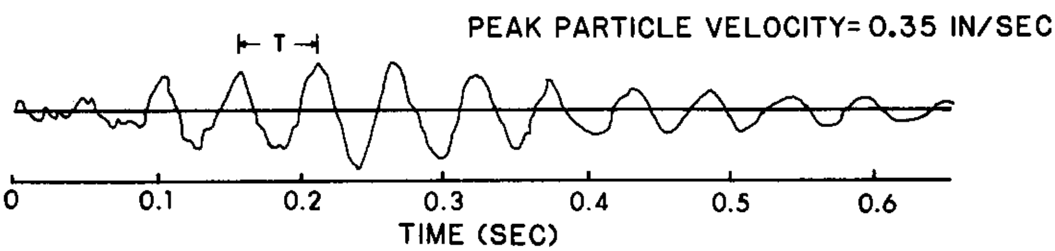
A structure, like a tuning fork, will vibrate at a fundamental natural frequency when excited. The maximum response of a house to blasting vibration occurs when the frequency of the ground motion matches the natural frequency of the house. On the other hand, when there is a mismatch between the ground vibration frequency and the natural frequency of the house, very little energy is transmitted into the structure.

This dependence on both particle velocity and frequency is the rationale for the OSMRE blast vibration regulations. Recent US Bureau of Mines research has determined that the fundamental natural frequency of low rise (1 or 2 story) residential structures is in a range of 3 to 12 Hz. These low frequencies are more predominant at greater distances from a blast, and this is the reason for the more restrictive particle velocity limit of 0.75 inch per second at distances beyond 5001 ft. from the blast site. At close in distances, up to 300 ft. from a blast, high frequencies (above 40 Hz) predominate the vibration record. These higher frequencies are well above the fundamental natural frequencies of residential structure, so a higher particle velocity limit of 1.25 inch per second is allowed.

When the ground vibration frequencies can be shown to be higher than 30 Hz, then the blaster would be permitted a peak particle velocity of 2 inches per second regardless of the distance away from a blast, by using the Alternative Blasting Level Criteria shown in Figure 1 [Section 816.67(d)(4)(i)&(ii)], Figure 12 in this Manual, page 24.

The Alternative Blasting Level Criteria permit the most accurate prediction of blast vibration effects, provide the best defense in the event of litigation and offer minimum restrictions on blasting procedures and therefore, the optimum potential efficiency and cost savings, while still offering maximum protection to the homeowner. In order to be able to use these Alternative Blasting Level Criteria, it is necessary for the explosives user to determine the frequency content of the blasting vibrations.

The frequencies present in a ground vibration seismogram are a result of three effects: the source, the geology of the travel path from the source to the seismograph, and the geology of the seismograph location. The blast frequency spectrum may be quite simple with the energy concentrated in one narrow frequency band. Such a condition would obtain at larger distances from a blast, when higher frequency components have been attenuated. Figure 41 is an example of such a relatively simple waveform. As can be seen, it is only necessary to determine the time interval between two adjacent peaks in order to calculate the frequency.



PERIOD = T = 0.054 SEC

FREQUENCY = 1/T = 1/0.054 = 18 Hz

Figure 41.
Calculation of frequency for a simple waveform.

For such simple waveforms, the frequency can easily be determined by measuring the time required for one oscillation of the waveform.

A more sophisticated method to determine the frequency content of a blast vibration recording would be a Fourier analysis. Because a blast vibration recording is not a continuous event, that is, it starts at a specified time and has a limited duration, it is called a discrete signal. In addition, the particle velocity levels are not necessarily periodic in that the peak values do not remain constant from one cycle to another, but vary, usually having the largest peaks early in the waveform and decreasing with time later in the waveform. As a result of having these properties, the Fourier transform will calculate only the relative amplitudes of the vibration frequencies contained in a waveform, but will not enable one to assign a peak particle velocity to any particular frequency. The plot of a Fourier amplitude spectrum normalized to the maximum peak particle velocity of the entire waveform can be used to estimate the particle velocity contributions for the various frequencies present. Such an estimate would be conservative, in that the overall waveform peak particle velocity is a result of contributions from all the frequency components present. This subject will be discussed in greater detail later in this chapter.

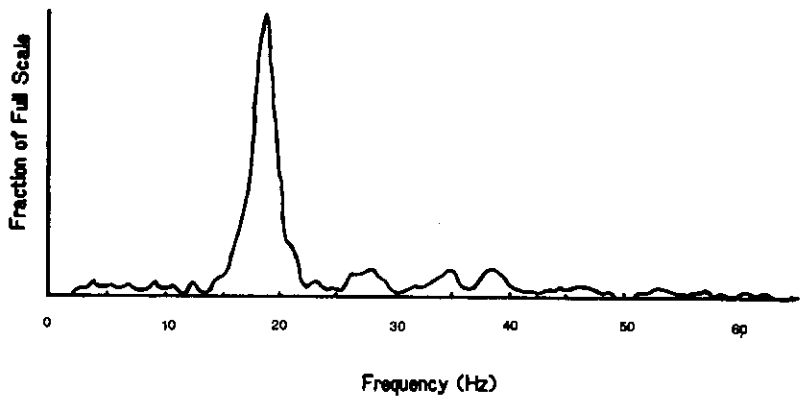


Figure 42.
Fourier amplitude spectrum for a simple waveform.

The plot of the Fourier amplitude spectrum for the simple waveform previously discussed is shown in Figure 42. It can easily be seen that the amplitude at 18 Hz predominates the spectrum. The overall peak particle velocity of the entire waveform was 0.35 inches per second. For this specific particle velocity recording, the 0.35 inches per second can be assumed to be almost entirely composed of 18 Hz energy.

A complex waveform results when two frequency components are present. These frequencies could represent the between hole and between row delay periods, or one frequency could be from the effects of soil thickness at the seismograph location, and the second frequency from a repetitive firing time in the blast design.

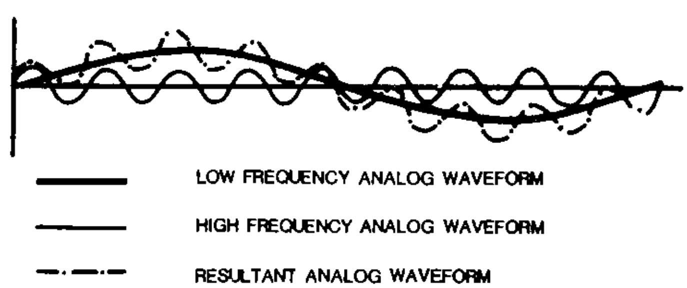


Figure 43.
Analog waveform with high and low frequency components.

Figure 43 shows a waveform made up of a high frequency and a low frequency component. The particle velocity of the low frequency component is twice that of the high frequency component. In this particular example, the particle velocity for each frequency component can be measured directly from the waveform. Figure 44 represents a more complex waveform which results when two frequency components are present, having equal particle velocities, but different phase relationships. It would not be possible to analyze this waveform by direct measurements, since the peak level is dependent on not only the particle velocity of each component but also on the phase relationship.

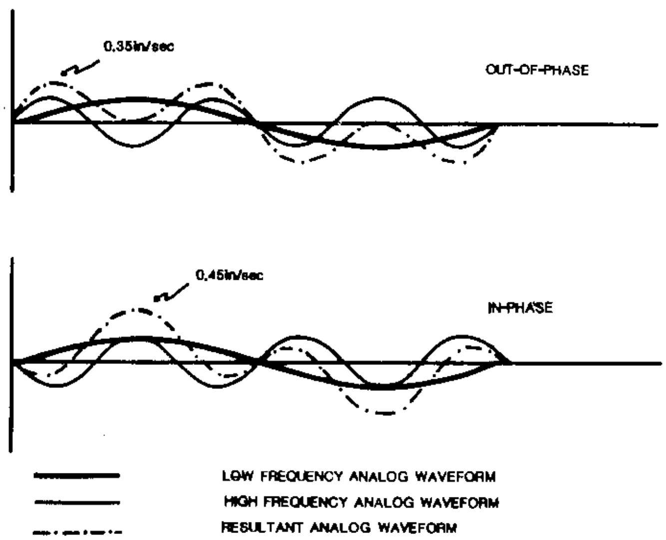


Figure 44.
Analog waveform with two frequencies
showing the effect of phase relationships.

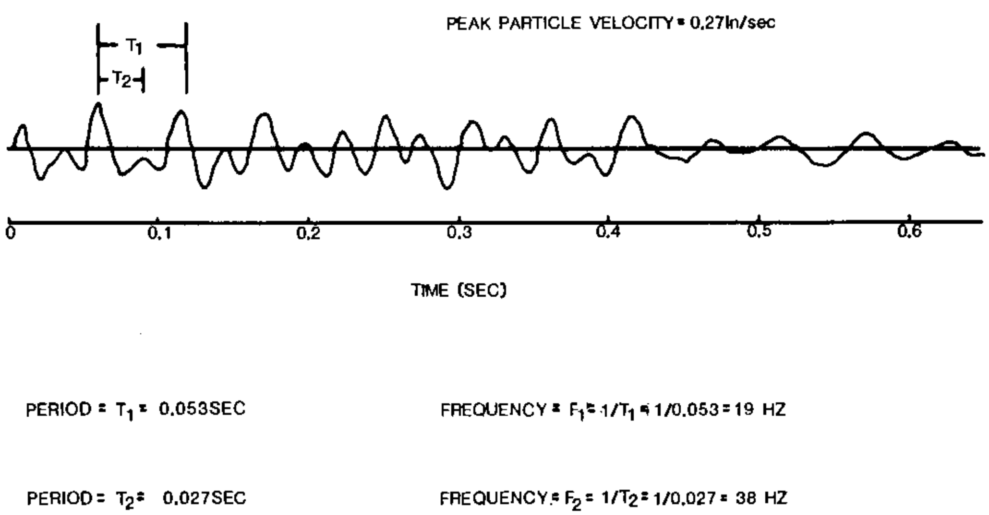


Figure 45.
Calculation of frequency for a waveform
with two predominant frequencies.

Frequency Considerations

Figure 45 is an actual blast vibration record containing two frequency components. The period for one frequency is .053 seconds (19 Hz) and for the second frequency the period is .027 seconds (38 Hz). Calculating the particle velocity for each of these frequencies is more difficult than for a simple wave having only one frequency present.

One method of determining the particle velocity of each of the frequency components would be to filter the original waveform to pass only that frequency to which it is desired to assign a particle velocity. If the blast vibration waveform has been recorded on magnetic tape, then analog or digital filtering would be done to selectively pass those frequencies of interest. The waveform in Figure 44 has been filtered using digital methods to first pass only the 38 Hz component, and then to pass only the 19 Hz component. These results are shown in Figure 46. The Fourier amplitude spectrum for this blast (Figure 47) shows similar results, in that the amplitude of each of the two frequencies are approximately equal.

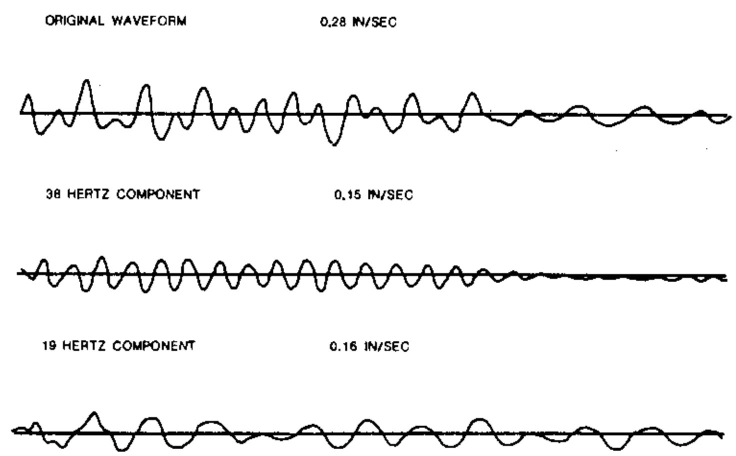


Figure 46.
Results of digital filtering.

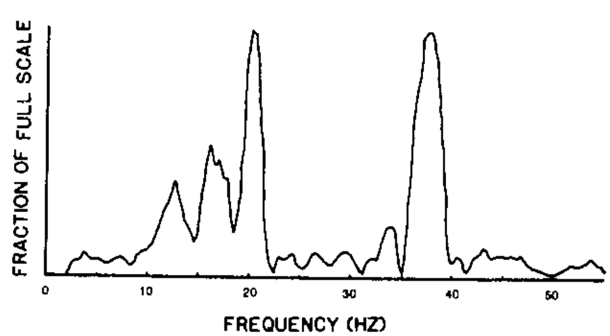


Figure 47.
Fourier amplitude spectrum for a waveform with two predominant frequencies.

An even more complex waveform is shown in Figure 48. The Fourier amplitude spectrum shows three frequencies present: 8, 19 and 42 Hz. The results of digital filtering show the particle velocities associated with each frequency.

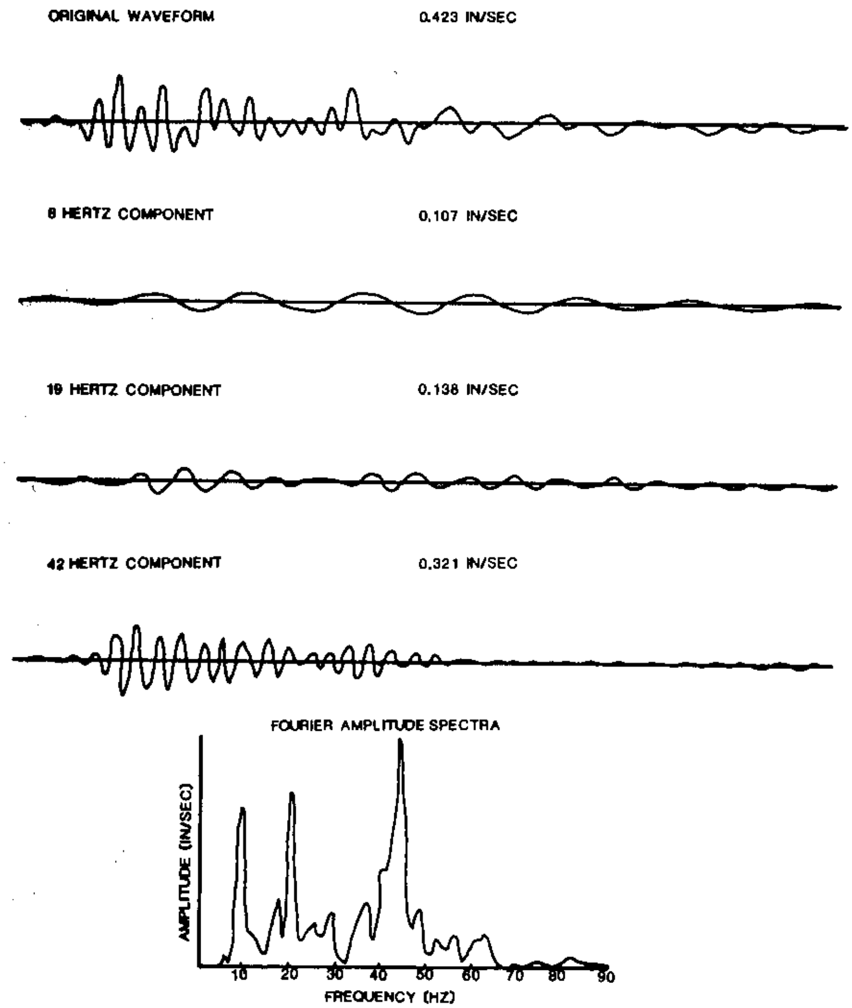


Figure 48.
Analysis of blast vibration waveform
with three frequency components.

An alternative method to determine the frequency content of a waveform would be to calculate a response spectrum. These response spectra can be used to predict how structures will respond to blasting vibrations. A structure is defined as a single degree of freedom model having mass, stiffness and damping. The actual values of mass and stiffness need not be known, since the effect of both factors determine the system's natural frequency. The model needs only to be defined in terms of natural frequency and damping. Damping is a measure of the frictional loss of energy in the structure as it vibrates. The response spectrum, while it can be used to determine the dominant frequencies present in the ground motion, contains much useful information on how the structure is responding.

The response method calculates the maximum relative motion between the ground and a structure of a specific natural frequency. The range of structure natural frequencies for which this maximum relative motion has been calculated on Figure 49 is 3 to 50 Hz. The response spectrum normalized to the maximum peak particle velocity can than be used to estimate the particle velocity contributions from the various frequency components. As can be seen on Figure 49, the normalized response spectrum gives conservative approximations of the peak particle velocities calculated by the use of digital filters.

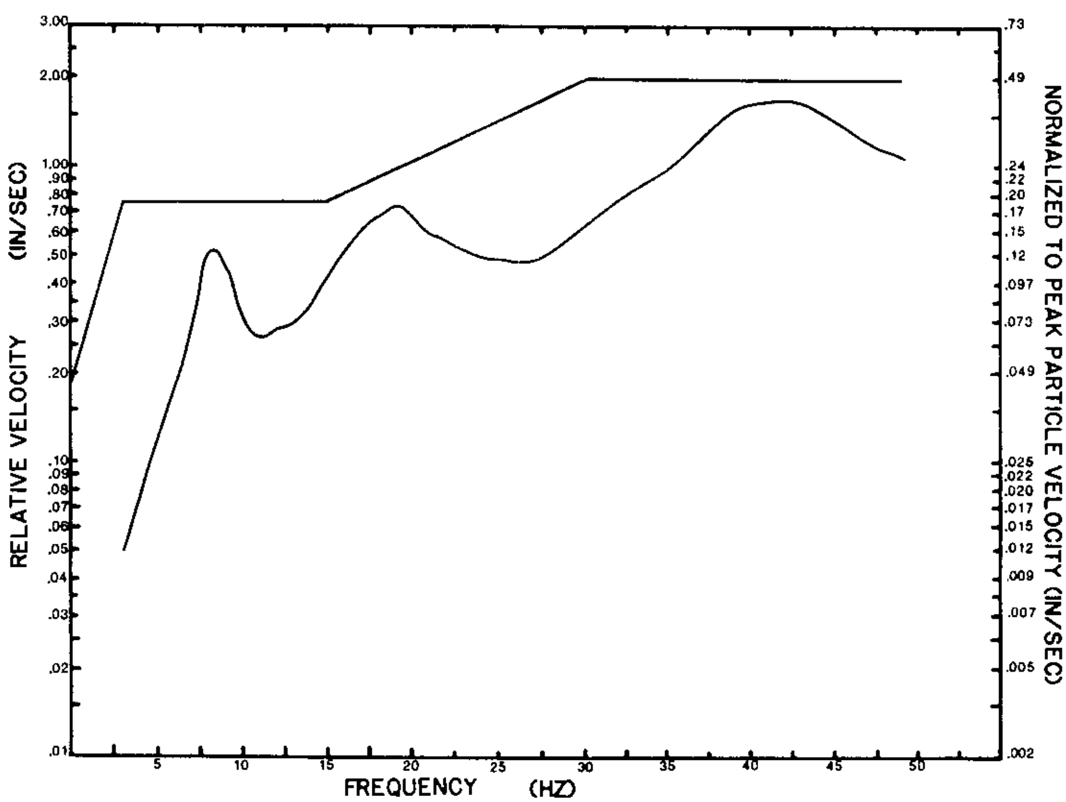


Figure 49.
Response spectrum of a blast vibration waveform
with three frequency components.

Further information on this subject may be found in the Medearis report "The Development of Rational Damage Criteria for Low Rise Structures Subject to Blasting Vibrations", and in the Dowding report "Cracking and Construction Blasting". In addition to these, the reader is referred to the two leading Bureau of Mines publications, RI 8485 and RI 8507, that deal specifically with frequency considerations.

In concluding this chapter, it is appropriate to refer again to the preamble to the Rules and Regulations (Federal Register, Vol 48, No.46, Tuesday March 8, 1983), where on page 9800: ".... OSM acknowledges that response spectra analysis as used in the RI 8507 study (Siskind and others, 1980) and by vibration consultants provides a unique solution because it sets allowable limits accurately by predicting the range of potential damage .... This technique if applied on a case by case basis might prove to be the best substantiation of the actual damage range. In order to allow such technique, and to provide operators the option to increase velocities above the maximum limits set for general compliance, OSM has included in Section 816.67(d)(4) an alternative method using Figure 1."

CHAPTER 12

RECORD KEEPING

Records should always be made by a responsible person at the time of the event. This responsible person should be, or be delegated by, the certified blaster, under whose direction all blasting must be conducted. A blaster is required to be present at all shots, together with at least one other person [Section 816.61(c)(3)].

It goes without saying that a blast vibration seismogram alone, unsupported by adequate records, is virtually useless. Even when the instrument itself can be programmed to record the date and time automatically, or when the sound channel possesses a 'VOICE' function to permit verbal comments and information to be recorded on the magnetic tape together with the blast, seismograph records <u>must</u> be supported by proper written records.

All blasting operations, whether or not they are subject to <u>any</u> regulations, must always be fully documented. This is quite apart from any consideration of compliance with OSMRE regulations. It is simple common sense to insist on a complete record keeping program wherever and whenever explosives are concerned. The risk of litigation is very real, and this risk alone should convince operators that good, clear, and complete records are essential. In the event of litigation, they are certain to be called into evidence; and as evidence they should be absolutely unassailable.

OSMRE regulations, in fact, establish a minimum standard for what should be regarded as the essentials of adequate blast and vibration records (Section 816.68):

- They must be kept at least 3 years. It is wise to keep them for much longer.

- They must contain the name of the operator conducting the blast.

- They must include the location, date and time of the blast.

- They must be signed by the certified blaster conducting the blast, and show his or her name and certification number.

- They must identify the nearest dwelling, public building, school, church, community or institutional building outside the permit area (except those described in Section 816.67(e)) and establish the direction and distance from the nearest blast hole to that nearest structure.

- They must note weather conditions, including those which may cause possible adverse blasting effects.
- They must record the type of material blasted.
- They must incorporate sketches of the blast pattern, including number of holes, burden, spacing, decks and delay pattern.
- They must specify the diameter and depth of holes, and the type and length of stemming.
- They must record the types of explosives used, the total weight of explosive used per hole, and the maximum weight of explosives detonated in any one 8 millisecond period.
- They must specify the initiation system.
- They must provide details of mats or other protections used.

These details must always be provided for any blast, irrespective of whether or not vibration monitoring is to take place.

If vibration monitoring is required by OSMRE regulations, then the following information must also be included in the records:

- Type of instrument; sensitivity (or "range setting") and calibration signal or certification of annual calibration.
- Exact location of instrument, and the date, time and distance from the blast.
- Name of the person and firm (can be the operator) taking the reading.
- Name of the person and firm (can be the operator) analyzing the seismographic record.
- The vibration level and/or airblast recorded.

The above vibration monitoring records are also the minimum necessary to support any seismogram or airblast recording, even if monitoring is not required by regulation. If monitoring is carried out, for whatever reason, it cannot be over emphasized that proper records must be kept. Attempts have been made in the past to reconstruct "blast records" from explosives supply invoices, and to develop support for seismograms from memory. Such poor record keeping must never be tolerated. In the event of litigation, the absence of such documentation places a defendant in an extremely precarious position.

One point that sometimes causes a certain amount of confusion, and that can lead to argument, is the "shot to structure or instrument" distance. The regulations require recording the direction and distance from the nearest blast hole to the nearest structure. From the point of view of vibration data collection and vibration prediction, where the scaled distance is the basic criterion, it is important to measure the distance from the center of the group or row of holes that represent the maximum charge weight per 8 ms delay. It may be that two or more groups of holes having similar charge weights per delay may have to be considered. In that event, the distance recorded would be that distance - and charge weight per delay - that resulted in the lowest scaled distance. In most cases, only academic differences will be observed; but in case significant differences do appear, both distances should be recorded and identified.

REPORT OF BLASTING OPERATION

County:________ Twp:__________

State: ____________________

Permit:________ Mine ID#______

Today's Date:________ Time of blast:________ (Military Time) Location of blast:____________________

Supervisor, in-charge of blast: Name:______________ Signature:____________________ Lic.#________ (Do not Include)

Distance form nearest hole to: (Circle one) Dwelling, School, Church, Commercial or Institutional bldg.:____________ft. (Company Owned or) (Leased Property)

Direction to property: N S E W Weather Conditions at time of blast:( ) Cloudy_____, Clear_____, Partial Overcase________

Temp.______, Barometric Reading_____, Wind Description__________ Remarks____________________

Material blasted:( ) Overburden_____, Parting_____, Other______ Explain____________________

Total number of holes shot:________ Burden_______ft. Spacing________ft.

Depth of holes: From:_________ft TO _________ft. Diameter of holes:_____________inches.

Type of explosives used:( ) AN-FO-Bagged_____, Bulk_____, Other_____ Explain____________________

____________________ Total weight of Explosives used:____________# Decking: Yes No

Max. pounds detonated within any 8 ms period:________# Max. number of holes detonated with any 8ms period:____________

Method of detonation:( ) Nonel_____, Electric cap_____, Other_____, Explain____________________

Type of circuit used:( ) Series_____, Parallel_____, Nonel_____, Other_____ Explain____________________

Stemming information: Type used:___________, Depth:_________ft., Was protective cover used? Yes No

Type of delay detonator used:______________. Minimum delay periods_____________millisecond.

Distance from nearest hole to seistector:__________ft. Exact location of seistector:______________

Name of mine personnel servicing seistector: (print)____________________

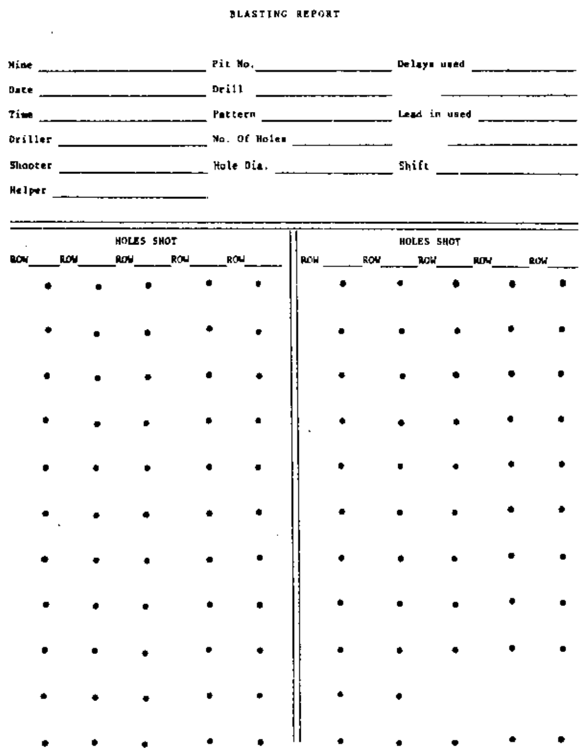
To be completed at a later date:

Name of firm analyzing seistector print-outs:____________________

Name of person analyzing print-outs:____________________

Seistector reading of this blast:____________________

Figure 50.
Typical blast record form.


BLASTING REPORT

Mine ______ Pit No. ______ Delays used ______

Date ______ Drill ______

Time ______ Pattern ______ Lead in used ______

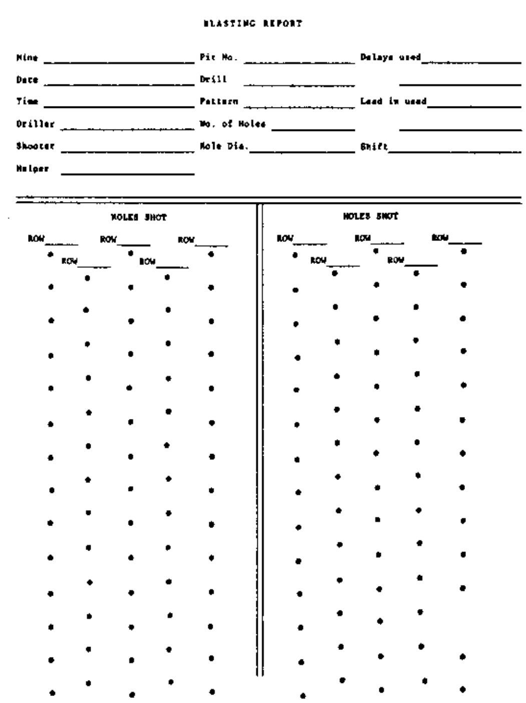
Driller ______ No. Of Holes ______

Shooter ______ Hole Dia. ______ Shift ______

Helper ______

HOLES SHOT — ROW ROW ROW ROW ROW | HOLES SHOT — ROW ROW ROW ROW ROW

Figure 51.
Blasting report (1).


BLASTING REPORT

Mine ______ Pit No. ______ Delays used ______

Date ______ Drill ______

Time ______ Pattern ______ Lead in used ______

Driller ______ No. of Holes ______

Shooter ______ Hole Dia. ______ Shift ______

Helper ______

HOLES SHOT — ROW ROW ROW ROW ROW | HOLES SHOT — ROW ROW ROW ROW ROW

Figure 52.
Blasting report (2).

Record Keeping

Figure 50, on page 103, shows a typical blast record form that provides the operator with an efficient and complete record of each event. It can include seismograph records, and can be used in conjunction with Figures 51 and 52, opposite, to provide sketches of the blast and delay pattern.

Figure 53, below, shows a representative blast and seismograph analysis form, as provided by a consultant for use with his instrumentation. Figure 54, on page 106 shows another example of this, with a slightly different format. In this case, the form is provided with carbon copies which may be retained with the operators blast records.

VIBRA-TECH BLAST AND SEISMOGRAPH ANALYSIS

Company ______ Operation: Name ______ Coal ☐ Quarry ☐ Constr. ☐
______ State ______ Other ______

BLAST DATA

Shot No. ______ Burden ______ ft. Total Explosives ______ lbs. Max. Explo./Delay ______ lbs. Delay Nos. ______
Date ______ Spacing ______ ft ______ ______ lbs. Max. Holes/Delay ______ Delay Mfr ______
Time ______ Diameter ______ in. ______ ______ lbs. Dist. Nearest Bldg. ______ ft. No. of Timer Circuits ______
No. Holes ______ Stemming ______ ft. ______ ______ lbs Dir. Nearest Bldg. ______ Timer Interval ______ ms
Depth ______ ft. Stem. Type ______ ______ ______ lbs. Weather ______ Blaster ______
Exact Blast Location ______ Blaster's Comments ______

SEISMOGRAPH DATA

Exact Location of Seis ______ Dist. To Seis. ______ ft
Seis. No ______ Cassette No. ______ Operator ______ Meters { Particle Velocity ______ ips
Range ______ ips Trigger Level ______ ips Witness ______ Air Overpressure ______ dBl

VIBRATION MEASUREMENTS

(FOR VIBRA-TECH USE ONLY) (FOR VIBRA-TECH USE ONLY)
Transverse ______ in/sec. Peak Ground Vibration is (within) (in excess of) ______ limit of ______ in/sec.
Vertical ______ in/sec Peak Air Overpressure is (within) (in excess of) ______ limit of ______ decibels
Longitudinal ______ in/sec. Analyst's Remarks ______
Overpressure ______ dBl ______ Analysis By: ______

(USE REVERSE SIDE FOR BLAST DIAGRAM)

Figure 53.
Typical blast and seismograph record form (1).

Pre-blast and post-blast surveys also need very careful record documentation. Whether the initial survey employs written or tape recorded notes, it is essential that complete contemporaneous records be kept that will:

- Identify the property, property owner, and date and time of the survey.
- Identify the person making the survey, and the operator.
- Determine the condition of the structure, document any pre-existing defects and positively relate any photographic or separate tape records to the body of the report. (Figure 55 shows typical pre-blast inspection forms that can be employed for the written methods of defect recording.)
- Assign identification numbers to all photographic negatives as they are exposed, retaining these numbers through to the final report. Any unused, or spoiled frames should be explained.
- Identify particularly historic or fragile buildings or specially valuable and fragile contents that might be particularly vulnerable to blast vibrations, as discussed in this Manual on page 9, and as required under Section 850.13(b)(10)(iii).

Recording #________ Client: ________ Job Location:________

Reported By: ________ Title:________ Seis.#________ Camera #________

BLAST DATA		SEISMIC DATA		FOR USE BY VME ONLY
Date	______	Seis. Range	0.25 1.0 4.0 (circle setting)	
Time	______	Digital Readout:		
No. of Holes	______	L______		L______
Max. #/Delay	______	V______		V______
Total Chg.	______	T______		T______
Distance	______	R______		R______
Location of shot point	______			Sound ______
				Scale______
Comments	______	Test Location	______	

FOR VME USE ONLY: REPORTED BY: ________ DATE: ________ COMMENTS: ________

Figure 54.
Typical blast and seismograph record form (2).

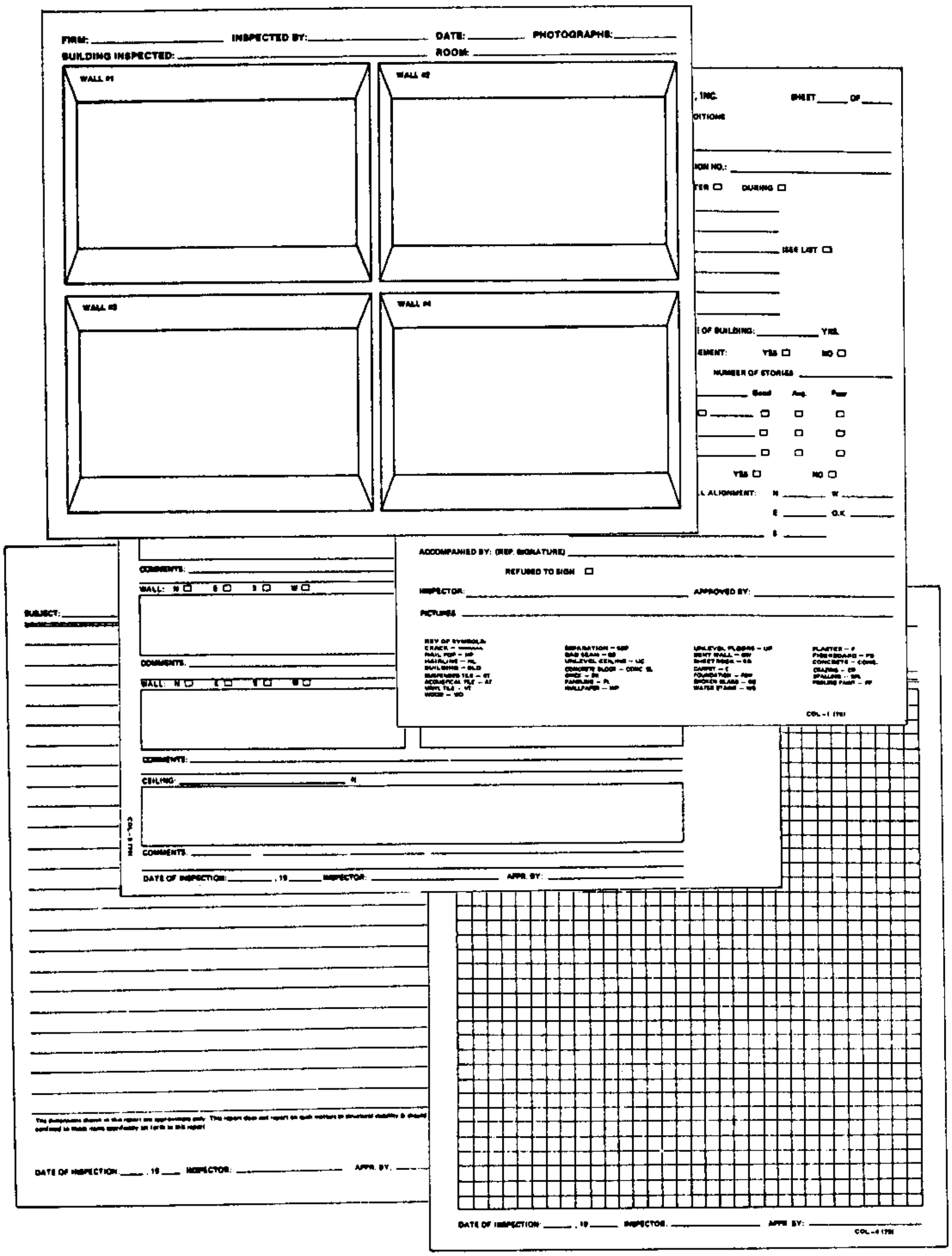


Figure 55.
Typical pre-blast inspection forms.

CHAPTER 13

CITIZEN INTERESTS: RIGHTS, PROTECTION AND INFORMATION

This section of the OSMRE Blasting Guidance Manual is specifically directed to the Citizen, whose safety and property are protected by the OSMRE regulations. All the other sections are for the information and guidance of the Mine Operator, so that he may properly comply with the requirements of the regulations, and therefore ensure the safety of the citizen's person and property. This section will provide the citizen with information on his rights under the law, how the regulations will protect and assist him, where he may go to obtain protection, and information on just what to expect in terms of perceived blasting effects, and what to look for when blast vibration damage is suspected.

RIGHTS AND PROTECTIONS UNDER OSMRE REGULATIONS

LONG TERM: Initially, before a mine is permitted, the citizen is free to exercise the most powerful right that he has, during the actual permitting process, to express any objections he may have to the mine being there in the first place. Since this manual is to guide those involved in an existing mine, miners or citizens, the premise will be made that the mine has been permitted, and is, or shortly will be, in operation.

The citizen is assured that public or private lands which are subject to surface mining will be reclaimed and returned to substantially the same form and condition as they were prior to the mining operation. Obviously, the time element involved will be long term, since many mines will have "lives" of ten, fifteen, or twenty years, and even longer in some cases. The State Regulatory Authority or OSMRE will be able to advise on the projected length of time that any mine is planned to remain in operation.

When mined land is reclaimed, the law requires that the original contours are restored to as practical an extent as possible, that the original water courses, and availability of surface and ground water, are not changed, inside or outside the permit area. Local features and wildlife habitat such as rocky outcrops have to be restored in a reasonable manner, while topsoil must be replaced and vegetation must be reseeded. That these regulations are in fact proving both practical and effective can be evidenced by a visit to virtually any modern surface coal mine, particularly in the Western grasslands. The public are frequently unaware that the land that they are viewing has already been mined through and reclaimed: at first glance it is frequently taken for virgin, unmined land.

SHORT TERM: The law also provides protection for the citizen from the short term effects of surface coal mining. These short term effects largely derive from the "adverse effects" of blasting that are specifically addressed, to the mine operator, in Chapter 3 of this Manual. Although the long term effects and protections mentioned on the preceding page refer to permitting, reclamation and non-blast considerations that are strictly outside the scope of this Manual, the short term effects - generally from blasting - are very much within its scope, and are therefore discussed in detail for the benefit of, and better understanding by, the citizen. From the citizen's point of view - understandably sometimes somewhat different from that of the mine operator - the protection provided by the regulations can be summarized as follows:

- The prevention of injury to persons.
- The prevention of damage to private property outside the Permit Area.
- The prevention of damage to public property outside the Permit Area.

The citizen will notice, however, that this does not provide any real degree of protection against annoyance. This is understood, and this particular point will be discussed - hopefully to the citizen's satisfaction - later in this chapter.

THE PREVENTION OF INJURY TO PERSONS

Explosives themselves are a great deal safer to use and to handle than most people generally imagine. This is not to say that explosives are not potentially dangerous: of course they are, and they should only be used by experienced and trained personnel, working under the supervision of a Certificated Blaster. Dynamite is now very little used in production blasting anymore except as a "primer" to detonate or initiate the main charge, most probably a "blasting agent" rather than a "high explosive". A stick of dynamite, however it might be portrayed in an adventure movie, is in fact considerably safer to handle than is a gallon can of gasoline! The main risk that might be incurred from handling dynamite, particularly with bare hands on a hot day, would be to develop a very severe headache, due to absorption of nitro-glycerine through the skin! Accidents can happen, however, and it is for that reason, amongst others, that OSMRE demands proper experience and training. The citizen will not be exposed to this risk, of course, and therefore the only possible way in which personal injury could result would be from "flyrock".

Flyrock and the dangers attendant to it are described in Chapters 3 and 4, pages 20 and 21, and 30 and 31. Flyrock can even cause death, and therefore the regulations take this hazard very seriously indeed, as it is without doubt the most dangerous single adverse effect of blasting.

Having established that, how do the regulations protect the citizen? Since there is no practical way to guarantee that flyrock will never occur - some "fly" or "throw" is actually normal to most blasting operations, and blasting mats or dirt cover have to be used for maximum control - the obvious way to eliminate the danger is to prevent flyrock from occurring where people can be present, or to prevent people from being where flyrock might present a danger. The regulations therefore mandate that flyrock must travel no more than half the distance to the nearest occupied dwelling or other structure, beyond the posted blasting control area, or beyond the permit boundary. This is also the fundamental reason why unauthorized persons are not permitted to be inside these areas.

Any citizen who is threatened by flyrock outside these areas has immediate cause for reporting a violation of regulations.

It would be difficult to imagine how the other two adverse effects of blasting, ground motion and air blast, could cause personal injury under any normal circumstances, certainly to any person who was not a member of a blasting crew, and when an accidental detonation did not take place. From the viewpoint of the citizen, it is reasonable to assert that the only risks presented by these effects would be to property.

THE PREVENTION OF DAMAGE TO PROPERTY

Without question, the most common single cause of damage to property resulting from blasting operations is due to flyrock. Obviously, the regulations to protect the citizen from injury will also protect his property from damage, and should damage occur from flyrock, it is also evidence of a violation of the regulations. The evidence is also virtually indisputable, except, as noted on Page 31, in the case of windshield glass breakage, or hail damage to vehicles.

While ground motion, or vibration, is the second most common cause of damage, it is nevertheless only truthful to point out that actual damage due to blast vibrations is in fact quite rare. This is mentioned as much to stress the very careful and conservative nature of the OSMRE regulations on vibration limitations, than to defend the mine operator.

These limitations, shown on pages 22-25 of this manual, allow under some circumstances up to 2.0 inches per second particle velocity, and under others as low as 0.2 inches per second, because of the different damage effects of ground motion of varying frequencies. This also explains the apparent anomaly of permitting higher velocities at short distances, because the frequencies of ground motion are higher at short distances, and higher frequency vibrations have been found to be less damaging. Although the Bureau of Mines research which forms much of the basis for the OSMRE regulations has shown that there is a possibility of minor damage at velocities even slightly below 1.0 inch per second, in normal conditions, with properly constructed buildings, damage is unlikely to appear at velocities under 3.0 inches per second. Whenever damage is referred to in this context, it is also necessary to remember that minor, threshold, cosmetic damage is what is meant. (See Chapter 4, page 29.) When major, structural damage, such as the collapse of brickwork, extensive and serious cracking threatening structural integrity, or concrete cracking is found (apart from the small drying-out or temperature cracks to be found in virtually all concrete) then either the ground motion exceeded 3 or 4 inches per second, or some other reason exists for the damage. See "CAUSES OF STRUCTURAL DEFECTS" on pages 4 to 6 of this manual.

If an operator is in compliance with the regulations, the citizen's house will be effectively protected from damage, even when the blasting vibrations are repeated on a daily basis over a period of years. It is a relatively simple thing to check on whether an operator is in compliance, and that is by measuring - or "monitoring" - the vibrations over a period of time. Many mine operators own or rent monitoring instruments, and most will readily accede to a request from a householder to monitor vibrations in this way. Blast vibration consultants, too, will be happy to carry out this service, either in person, or simply by means of an instrument rental for a short period. Most available instruments are very easy to use, and are quite impartial: they will accurately report a vibration level regardless of who owns them, or who switches them on!

If velocities in excess of the regulatory levels are recorded, then regardless of the method of regulatory compliance that the operator has chosen (See Chapter 9, page 73), it will be apparent that the operator is in violation of the regulations. This is because the "scaled distance" option is so safe and conservative that it is almost impossible to exceed regulatory vibration levels when it is used. In any case, should this situation arise, subsequent seismic tests would be able to establish this possibility. If the operator is using one of the velocity limitation options, then there would be no question at all.

Where airblast is concerned, although this is the effect that causes the most annoyance of all, it is also the effect that causes the least damage. Airblast that can cause even minor damage is so much higher - some 10 to 15 times higher - than the maximum allowed under the OSMRE regulations, that it can virtually be discounted as a possible cause of damage. In any event, whenever airblast does cause damage, it always shows up first as broken window panes. If a building suffers structural damage, and it does not have any broken windows, then the cause was other than airblast.

This, then, is one area of the regulations where annoyance plays as much a part in the thinking behind the regulations as does damage. It does not totally eliminate the problem, but it does bring it within reasonable bounds. Airblast can be monitored, in the same way as ground motion, and if an airblast level is measured at an occupied dwelling that is in excess of the regulatory limits, then the mine operator is in violation of the regulations.

In fairness to the operator, it might also be stated that airblast is the most difficult of all the adverse effects of blasting to control, because of the many weather and atmospheric variables, and other factors outside the control of the mine operator. OSMRE does not of course condone at any time any breach of the regulations, and any such recorded breaches constitute violations regardless of the circumstances. OSMRE does however concede that an occasional airblast violation does not automatically indicate unwillingness to comply on the part of the operator.

PRE-BLAST SURVEYS

The OSMRE regulations are quite clear and specific on the rights of the citizen when it comes to the question of pre-blast surveys. Sections 816.62 (a), (b), & (c) require that a mine operator notify <u>all</u> residents living within a half mile radius of the mine permit area, at least thirty days before the blasting program is to begin, on how to request a pre-blast survey. The resident, or the owner of the property, may request that such a survey of his home be carried out, and this request may be made either to the mine operator, or to the regulatory authority. The mine operator may carry out the survey, or he may employ others to do this on his behalf. If he employs a third party in this way, that person is likely to be a professional consultant who is experienced in this type of survey. In either event, it will be carried out at no charge to the resident or owner of the property. The survey must be prompt, and the report of the survey, a copy of which must be supplied to the person requesting the survey, must also be prompt. If the resident or owner disagrees with the content of the survey, a detailed description of the areas of disagreement may be submitted to both the operator and the Regulatory Authority.

Updated reports of any additions, modifications or renovations must also be surveyed and provided by the operator to the resident or owner, if requested.

The pre-blast survey provides one of the most powerful protections and controls that it is possible to have on the often argued question of damage liability. A householder may be certain in his own mind that a particular crack or defect is the direct result of blasting activity at the neighboring mine. If a pre-blast survey does not record such damage, and inspection and investigation of his complaint shows the defect to be there, then there can be no further argument. Note that in this case the purpose of the survey is not to determine whether the operator is in violation of the regulations or not. The operator is in compliance with the regulations, merely by carrying out the surveys as required. The survey itself simply determines whether any subsequent damage complaints are actually damage or not: obviously, if the determination is that the damage was caused by the blasting operation, then it is the operator's responsibility to repair or recompense the householder for that damage. OSMRE, however, cannot compel a mine operator to repair or recompense the householder. Restitution is often a legal matter.

The pre-blast survey also protects the mine operator from unjustified damage claims. Whatever defects are recorded prior to a blasting program cannot subsequently be claimed as blast vibration damage. A resident or owner does not <u>have</u> to submit to or request a preblast survey, but if he declines such a service it might well weaken any subsequent claim he might then make for damage he claims was suffered due to that blasting.

BLASTING TIMES AND SCHEDULES

Another protection provided to the citizen by the OSMRE regulations is the requirement that blasting take place in accordance with published schedules, and within specified hours. Blasting schedules must be published in a local newspaper at least ten days, but not more than thirty days, before the start of a blasting program. Copies of the schedule must be distributed to local governments and public utilities, as well as to all local residents within a half mile of the blasting site as described in the schedule. The operator must republish and redistribute the schedule at least every 12 months, at least ten days but not more than thirty days before blasting, whenever the schedule area or blasting times differ significantly from the previous information.

All blasting must take place during daylight hours unless more restrictive times are specified. If night-time blasting is approved by the regulatory authority, it must be based on evidence from the operator that the public will be protected from adverse noise and other impacts.

All other unscheduled or night-time blasts can only be conducted on an emergency basis, for reasons of operator or public health or safety. In such a case, the operator must notify all residents within half a mile by audible signals, and he must document the reasons for, and conditions of, the unscheduled blast. A typical example of such an unscheduled blast might be that the operator had loaded a shot, but had to vacate the area for safety reasons, say due to a thunderstorm. If night had fallen before the thunderstorm had ceased to threaten, and the operator felt that it was an unacceptable hazard to leave the loaded shot overnight, then he would be justified in carrying out the unscheduled blast, provided of course that he made notification of the blast and documented it properly, as required by the OSMRE regulations.

PERCEIVED BLAST VIBRATION EFFECTS

Thus far in this chapter vibration intensities have been referred to, unavoidably, in terms of "particle velocity". Normally, when a member of the public hears someone - mine operator, government official or consultant - speak of vibrations in unintelligible language - "point six five inches per second" - he cannot help but consider that it is just so much "gobbledygook" and that perhaps the "experts" are even trying to hide things from him. Why can't they speak in terms that everyone understands? Unfortunately, no-one has yet invented terms for this rather specialized field that everyone does understand.

What can be done in this chapter, however, that may at least alleviate this problem, is to discuss in simple everyday terms the way that human beings feel or perceive blasting vibrations.

First, there is no doubt at all that some people can feel vibrations almost as low as instruments can measure them. It is often commented that human senses are very dull compared to those of animals, though it is not often realized how keen in fact some of these human senses are! The sense of touch, for instance. Stretch a human hair across a smooth surface, or overlap two thin sheets of paper, and run a finger across, and few people will have any problem at all in feeling just two or three thousandths of an inch! Although many people these days - especially the young - have reduced hearing ability, the human body as a whole is astonishingly sensitive to ground vibrations. Levels can be felt that present absolutely no danger at all to structures. In fact, houses are vibrating much of the time to one extent or another. People, particularly heavy ones, or active children, generate motion that at times approaches - or even exceeds - the limits set by OSMRE. Climbing or descending stairs, jumping, door slamming or even just walking across a floor can cause considerable motion in a structure. The fact is that when people themselves are in motion, they do not notice any movement in the structure of their homes.

So how do most people react to, and actually feel blast vibrations? The most obvious effect is usually the airblast. Since it does not always contain frequencies that humans can best hear, it is not always a very loud event. It is usually perceived as anything from a dull thump to a loud bang. A loud bang is not always a "high" airblast, and conversely, a dull thump may in fact be one. It might even be inaudible! The house may well react, or respond, the structure may creak, the windows may rattle, and, if a person is not expecting it, it may be quite startling. It is most unlikely ever to cause damage.

Ground motion, or ground vibration, can be experienced in different ways. A very low frequency vibration, such as might be experienced from a large blast on a mine a long way off, might not be recognized as a vibration, only as sense of unease, or even a passing feeling of slight giddiness. Higher frequency and higher intensity motion is much more obvious and recognizable, particularly if the structure responds. Humans are frequently disturbed by vibration levels that are perfectly permissible under the OSMRE regulations. This is discussed in the manual under the heading of "HUMAN SUBJECTIVE TOLERANCE" in Chapter 5, pages 35, 36 and 37.

When vibration levels occur which approach or exceed the regulation limitations, there is no doubt at all that most people find this unpleasant, and their cause for alarm is normally quite justified. It is the reason why most consultants advise their clients to try to keep well below the regulatory levels, and only plan to risk approaching them when blasting in those locations must be carried out.

A common complaint involves the rattling of crockery. When a person is at rest in his home, and the vibration from a nearby mine blast causes the crockery to rattle, then he is disturbed by this, and frequently worries about whether such a vibration could have caused any damage to his home. In investigating such complaints, however, it is sometimes noticeable that the crockery rattles simply when a person walks across the floor. When this is pointed out, it may be that that person, in motion, just did not realize that this was happening. Sometimes, though, the person admits that knowing that the rattling is due to a normal household activity is not worrying, but when it happens due to action of explosives, then who knows what that might have done!

Apart from the normal activity of the occupants, a structure is subjected to daily, seasonal and incidental outside causes of motion. Some are very slight, and unnoticeable to the casual observer, such as daily and seasonal temperature changes. The structure, however, is nevertheless affected by such temperature, and therefore dimensional, changes. Seasonal moisture differences can cause the ground the house is built on to expand and contract. More obvious causes of structural movement are high winds, thunderstorms, and earthquakes. Nearby highways or railroads, and of course airports, can all cause vibrations.

Even unoccupied dwellings, if left undisturbed, will eventually deteriorate to the point of collapse.

ACTUAL BLAST VIBRATION EFFECTS

One very important consideration concerns the response of a structure to a blast vibration. This has already been referred to briefly above. Rather like the wine glass that was shattered by the opera singer holding a sustained note, a structure has a "natural" frequency at which it will vibrate when "excited". When an incoming ground motion is at that same natural frequency, then the structure is "excited", and the resulting response can well exceed the intensity of the incoming ground motion. This again is the reason why the regulations permit higher vibrations at high frequencies than they do at low frequencies. Because of this also, since this phenomenon has already been taken into account, the regulations control the incoming ground motion only. From the point of view of perception, therefore, a person will be less disturbed by a blast when he is outside his house than when he is inside it. From the viewpoint of actual effects, however, the citizen may well have noticed the potted plants on his window sill vibrate, and he may consider it reasonable to request that vibration measurements be taken on the window sill. The mine operator would be justified in declining that request, as it would only measure the response of the structure at that point, and not be a valid measurement of ground motion under the OSMRE regulations.

When frequencies are very low, about 4 to 12 Hz, and structures respond, then the maximum danger of actual damage occurring exists. A small possibility exists of damage at velocities even below 1.0 inch per second, which accounts for the low velocities allowed on the Blasting Level Chart, Figure 12 on page 24 of this manual. As frequencies increase, the likelihood of structural response decreases, and the allowable limits increase. The actual effect of a ground vibration close to, but not exceeding 2.0 inches per second, at a frequency at or above 30 Hz would be a highly <u>perceptible</u> vibration, and probably a very annoying one, but one that would not cause damage.

Incidentally, ground motion has to be far above these levels to threaten wells or aquifers, although these problems are frequently feared and complained of.

ANNOYANCE

The above discussion on perceived and actual vibration effects has had the central theme of annoyance running through it. Unfortunately, annoyance is very difficult to quantify, and it is further complicated by the fact that not all human beings are annoyed by the same things. Some of us simply do not worry about things that drive others crazy. It can also help to recognize that as far as a local surface mine is concerned, the citizen who originally tended to benefit from the operation, and who did not oppose the application, will be far less annoyed by the operation than the citizen who did oppose that operation, and who had to watch it become an established operation in the face of his objections.

Citizen Interests

For those who do find that they are annoyed by surface mining, and cannot help but be annoyed by surface mining, the following is a sincere discussion that they will hopefully find of some consolation, and that may even lead the way to a reconciliation with that annoyance.

Certainly as far as the the airblast limitations are concerned, annoyance was very definitely considered when the regulations were written. The airblast allowed by OSMRE is less than half the level allowed by OSHA for impulsive noise. Except in emergencies, or when specifically approved by the Regulatory Authority, as already discussed, no blasting is allowed at night, and the published schedules and notification system ensure that people are not taken by surprise or startled by the blasting.

Ground vibration presents a rather more difficult problem where annoyance is concerned, since humans are so sensitive, and can perceive - and be annoyed by - remarkably low, though certainly not damaging, levels of vibration. In order that explosives be used efficiently as a tool for breaking rock, it is sometimes necessary to generate vibrations that not only can be distinctly felt, but that some people might find find highly annoying. These can be perfectly legal levels, within OSMRE regulatory limits, and quite safe, presenting absolutely no risk of damage. Nevertheless, for many people, they can, and do, annoy.

A possible solution to the problem lies in efforts to establish and maintain good relations between the citizen and the mine operator. It is normal, of course, for the operator to promote such relations, but in order for the maximum mutual benefit to be derived from such efforts, the citizen should attempt to extend his own hand no matter how difficult this may at first seem to be. An unbiased attempt to achieve mutual understanding is often a good first step.

Understanding that the viewpoint of the operator is going to be significantly different than that of the citizen, and that this does not automatically signify an adversary situation, is a considerable step towards achieving good mine operator and citizen relations. Whereas it is sometimes the case that the citizen feels forced into an adversary situation by the mine, it can be that the mine, or at least some of its personnel, can feel precisely the same pressures. While the citizen feels that the mine threatens his peace, his environment, his residence, and his quality of life, the mine personnel can also feel threatened by citizen complaints, which seem to jeopardize their very livelihoods. If the accounts that they make of the same situation might be widely disparate, and would seem to prove that one or the other just cannot be telling the truth, patience and understanding may well show that this is not the case: both are being entirely truthful by their own lights.

Witness the blaster who tells the consultant arriving at the blasting site: "Those people on top of the hill! They're giving me fits! I've told them that there is nothing to worry about, but they complain every time I shoot! You will have to do something about them!"

The consultant sets up his instrument at their house, and finds that they are quite nice people, but rather afraid of the blasting. There is nothing strange about that.

They say to the consultant: "That dynamiting is getting on our nerves - the house shakes every time it goes off! The man that's doing it told us that there was nothing to worry about, but you should feel it when he blasts! You will have to do something about it, for we are worried about the damage it must be doing to the house!"

The consultant explains to them that he is there to make sure that the house is not damaged: that is what the instrument is for. The blaster, who has, and uses his own instrument, did not bother to explain this - after all, they were too busy complaining! The consultant also tells them that although the vibrations will not harm the house, they will certainly feel the motion, and may be bothered by it. He tells them that they will feel the vibrations much more strongly if they remain inside the house, and suggests that they stay outdoors.

The shot is fired, and the consultant notes the vibration levels: 0.15 inches per second, not nearly enough to cause any damage, but certainly enough for the people to feel, and even to alarm them if they are inside the house and there is any real degree of structural response.

They say to the consultant: "That was not as bad as you said it was going to be! But why did the blaster say we would feel nothing at all?"

The explanation is simply that the blaster, who is entirely familiar and comfortable with blasting and explosives, had told them merely what he believed to be true, that it was nothing to worry about, and that they wouldn't feel a thing. Once that was explained to the householders, together with the comment that the blaster had never been inside the house when he fired his shots, then a mutual understanding was established, and the foundation was laid for a better relationship in the future.

The whole direction of this manual to the Mine Operator is to enable him to comply with the OSMRE regulations, and therefore to minimize the adverse effects of that operation. It is certain that the citizen's safety and property will be protected. It is not always possible to control the physical effects of blasting operations to such an extent that people will not be aware of the activity. Mining does have some adverse effects, and the annoyance that derives from those effects is genuinely regretted. One cannot build highways and bridges or new developments or, for that matter, permit and operate mines without causing annoyance to some. These are all legal and even desirable activities, benefiting the majority of the people, and are sometimes essential to all of us. Certainly we are all dependent on our future energy supplies, and perhaps coal is even a more acceptable source of energy to most people than nuclear sources are. Some of this coal mining activity will cause annoyance. But with care and understanding, one can at least try to remove some of the sharpest edges from that annoyance.

ACTUAL BLAST DAMAGE CRITERIA

The Bureau of Mines research on blast vibration damage is detailed and extensive. Among the conclusions drawn by RI 8507 (see page 29 of this manual for this document's definition of threshold damage due to blast produced ground vibration) are the following:

- 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.

- Practical, safe criteria for blasts that generate low-frequency ground 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.

- 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 damage threshold when the vibration (from any cause, for instance slamming a door) could in some case precipitate a crack about to occur.

- 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 . . . (1-sec vibration) . . . should be tolerable to about 95 pct of the people perceiving it as "distinctly perceptible".

This, amongst other things, at least tells us that the Bureau of Mines research personnel experienced considerable difficulty quantifying and qualifying blast vibration damage! What sort of difficulty will the layman have when attempting to determine if he has suffered blast damage?

First, he will have to have been considerably startled or disturbed by the high level of the vibration, if he was there to observe it. If he was, and he actually observed damage occur, then he will have no doubts at all, and will be able to testify quite confidently.

Secondly, he will have to look for small, almost hairline cracks that are fresh, without dust, spider webs, insect detritus or paint inside them. Small fallen flakes of paint or plaster will be an indication, as will be the widening of existing cracks. One problem in determining whether an existing crack has widened, of course, derives from whether its original dimension was either known or recorded. Imagination can cause cracks to widen, especially if the observer is distressed.

Thirdly, he may observe cracks in the jointing paper covering the separations between gypsum wall and ceiling panels. Again, he should make sure that these are in fact fresh, for many such small imperfections can pass unnoticed for years until the householder fears that blasting may be harming his house, and he starts looking for signs of damage.

Many of these small cracks will typically run from the corners of openings such as doors or windows, or follow separations between building elements. Outside brickwork cracks, normally in the mortar between the bricks, will also follow the same pattern, running from the corners of openings, and also from lintel tops, or below sills. A "stairstep" crack is quite typical in brickwork, though a stairstep crack running diagonally from ground level near a corner to the wall corner above ground level, very often indicates settlement rather than blast damage.

Concrete, particularly reinforced concrete, is very resistant to blast vibration damage. Cracks will not normally appear in concrete below perhaps 10.0 inches per second, a velocity that is not only far higher than OSMRE regulations permit, but that would normally cause undisputed and quite extensive cracks to occur to plaster, gypsumboard and brickwork. Damage to concrete is therefore normally accompanied not only by exceptionally high velocities, but also by other, and obvious damage.

Whenever the citizen suspects, therefore, that his home is suffering from the effects of excessive blast vibrations, he should without delay carefully and thoroughly inspect the whole structure - or engage an expert to inspect it - or, within the terms of the OSMRE regulations and the comments on page 10 of this manual, request a post-blast survey. He should document, and measure, or mark and date, every crack, so that widening or lengthening of cracks becomes a matter of documentation and not mere imagination. If he is sufficiently expert in photography, he can support any evidence he may find with good, clear, photographs, but he must also document the photographs carefully so that no possible confusion can arise as to identification or location.

In fact, any concerned citizen, even if he is quite distant from the mine, and is not able to feel any vibrations, ground motion or airblast, should nevertheless inspect his home carefully from time to time. He will be able to see that his home presently has more defects than he might otherwise have imagined, and, should the mining operation approach closer, or use heavier explosive loading, when the vibrations will then become perceptible, he will be spared much worry and speculation.

SPECIFIC COMPLAINT PROCEDURES

STATES WITH APPROVED STATE PROGRAMS

If residents or homeowners believe that their property has been damaged, or that there has been a violation of any of the blasting regulations, they may register a formal complaint with the the State Regulatory Authority who has jurisdiction over the program.

A person may request an inspection of the mine where blasting is taking place. The request for an inspection should be a signed, written statement (or an oral report followed by a signed written statement) giving the State reason to believe that a violation exists. The statement should set forth a phone number and address where the person can be contacted.

The identity of any person supplying information to the State shall remain confidential if requested by the person. If the person elects to accompany the inspector on the inspection, anonymity cannot be guaranteed.

Within a specific period of time which varies from State to State, the person requesting the inspection must be informed of the results of that inspection, and a description of any enforcement action that was taken.

The complainant will be informed of the informal and formal review rights that he may have under State law and regulation if he is not satisfied by the action of the State. It must be kept in mind at this point that the inspection may take the form of a special investigation which may include the taking of seismographic readings. This very often can take several weeks.

Should the complainant not receive satisfaction from the State Regulatory Authority, he may request an inspection/investigation by the Office of Surface Mining Reclamation and Enforcement (OSMRE) Field Office with responsibility for program evaluation in that State.

In this case, OSMRE will review the action of the State Regulatory Authority and determine the course of action that it will take. Should a Federal inspection result, it will be carried out according to the procedures outlined in Part B of this secton, Federal Program States.

Should OSMRE receive a complaint or request for a Federal inspection, and it is determined that the State Regulatory Authority has not been contacted, OSMRE will refer the matter to the State for resolution.

FEDERAL PROGRAM STATES

These are States where OSMRE has primary authority to regulate coal mining and reclamation operations under Public Law 95-87.

A person may request a Federal inspection by furnishing any OSMRE office with a signed, written statement (or an oral report followed by a signed, written statement) giving the reason why (s)he believes that a violation exists. This statement must set forth a phone number and address where the person can be contacted.

The identity of any person supplying information to OSMRE shall remain confidential, if requested by the person requesting the inspection. If the person elects to accompany the inspector on the inspection, anonymity cannot be guaranteed. OSMRE will keep the person's name confidential unless required to disclose the name under the Freedom of Information Act (5 U.S.C. 552) or other Federal law.

If a Federal inspection is conducted, the complainant will be notified in advance when the inspection is to take place, and will be allowed to accompany the inspector during the inspection.

Within 10 days of the Federal inspection, or, if there is no Federal inspection, within 15 days of receipt of the person's written complaint, the Office will send to the person the following:

1. A description of the enforcement action, which may consist of copies of the Federal inspection report and all Notices of Violation and Cessation Orders.

2. If no Federal inspection was conducted, an explanation of the reason why.

3. An explanation of the person's right, if any, to informal review of the action or inaction of the Agency.

If a person is not satisfied with a decision or the results of an investigation into his complaints, he may ask the Director, OSMRE in writing for an informal review. The Agency has 30 days from the receipt of that request to inform the person of the results of that review.

The results of the informal review will also advise a person of his rights to formal review under Section 525 of Public Law 95-87.

The OSMRE will give copies of all materials associated with the results of the inspection/investigation to the person alleged to be in violation, except that the name of the person supplying information shall be removed unlss disclosue is required under the Freedom of Information Act, or if the person did not request confidentiality.

REGULATORY AUTHORITIES

OSMRE: WESTERN FIELD OFFICES

FIELD OFFICE & ADDRESS:	TELEPHONE NO:	RESPONSIBLE FOR:
Office of Surface Mining Reclamation & Enforcement Kansas City Field Office 1103 Grand Avenue, Rm. 502 Kansas City, MO 64106	(816) 374-5527	Iowa, Kansas, Missouri & Nebraska
Office of Surface Mining Reclamation & Enforcement Room 216 219 Central Avenue, N.W. Albuquerque, NM 87102	(505) 766-1486	Arizona, California, Colorado, New Mexico & Utah
Office of Surface Mining Reclamation & Enforcement Tulsa Field Office 333 West 4th St., Rm. 3432 Tulsa, OK 74103	(918) 581-7927	Arkansas, Louisiana, Oklahoma & Texas

Office of Surface Mining Reclamation & Enforcement Casper Field Office 100 East B St., Rm. 2128 Casper, WY 82601-1918	(307) 261-5776	Alaska, Idaho, Montana, North Dakota, Oregon, South Dakota, Washington & Wyoming

WESTERN FIELD OPERATIONS

Administrator Office of Surface Mining Reclamation & Enforcement Brooks Towers, 2nd Floor 1020 15th Street Denver, CO 80202	(303) 844-5421	All States west of the Mississippi River

OSMRE: EASTERN FIELD OFFICES

FIELD OFFICE & ADDRESS:	TELEPHONE NO:	RESPONSIBLE FOR:
Birmingham Field Office Office of Surface Mining 228 West Valley Ave., Rm. 302 Homewood, AL 35209	(205) 254-0890	Alabama, Georgia and Mississippi
Springfield Field Office Office of Surface Mining 600 East Monroe St., Rm. 20 Springfield, IL 62701	(217) 492-4495	Illinois
Indianapolis Field Office Office of Surface Mining 46 East Ohio St., Rm. 520 Indianapolis, IN 46204	(317) 269-2626	Indiana
Lexington Field Office Office of Surface Mining 340 Legion Dr., Suite 28 Lexington, KY 40504	(606) 233-7327	Kentucky
Columbus Field Office Office of Surface Mining 2242 S. Hamilton Rd., Rm. 202 Columbus, OH 43232	(614) 866-0578	Ohio & Michigan
Harrisburg Field Office Harrisburg Transportation Center 3rd Floor, Suite 3C 4th & Market Sts. Harrisburg, PA 17101	(717) 782-4036	Pennsylvania, Rhode Island, Massachusetts

Knoxville Field Office Office of Surface Mining 530 Gay St., S.W., Suite 400 Knoxville, TN 37902	(615) 673-4504	Tennessee
Big Stone Gap Field Office Office of Surface Mining P.O. Box 626 Big Stone Gap, VA 24219	(703) 523-4303	Virginia & North Carolina
Charleston Field Office Office of Surface Mining 603 Morris Street Charleston, WV 25301	(304) 347-7158	West Virginia & Maryland

EASTERN FIELD OPERATIONS

Administrator Office of Surface Mining 10 Parkway Center Pittsburg, PA 15220	(412) 937-2828	All States east of the Mississippi River

WESTERN STATE REGULATORY AGENCIES

STATE	AGENCY:	ADDRESS:	TELEPHONE:
AK	Department of Natural Resources	Pouch M Juneau, AK 99811	(907) 456-2400
AR	Department of Pollution Control and Ecology	8001 National Drive Little Rock, AR 72209	(501) 562-7444
CO	Department of Natural Resources Division of Mined Land Reclamation	423 Centennial Bldg. 1313 Sherman St. Room 424 Denver, CO 80203	(303) 866-3567
IA	Department of Soil Conservation	Wallace State Office Building Des Moines, IA 50319	(515) 281-5851
KS	Mined Land Conservation & Reclamation Board	107 West 11th St. P.O. Box 1418 Pittsburg, KS 66762	(316) 231-8540
LA	Department of Natural Resources	Office of Conservation P.O. Box 44275 Baton Rouge, LA 70804-4275	(504) 342-5528

MO	Land Reclamation Commission	117 East Dunkin P.O. Box 176 Jefferson City, MO 65102	(314) 751-4041
MT	Department of State Lands	Capitol Station 1625 11th Avenue Helena, MT 59620	(406) 444-2074
NM	Energy & Minerals Department	Mining & Minerals Division 525 Camino de las Marquez Santa Fe, NM 87501	(505) 827-5974
ND	Public Service Commission	Capitol Building Bismarck, ND 58505	(701) 224-2249
OK	Department of Mines	4040 N. Lincoln Blvd. Suite 107 Oklahoma City, OK 73105	(405) 521-3859
OR	Dept. of Geology & Mineral Indus.	1129 S. Santiam Rd. Albany, OR 97321	(503) 967-2039
TX	Railroad Commission of Texas	P.O. Drawer 12967 Capitol Station Austin, TX 78711	(512) 463-6900
UT	Dept. of Natural Resources, Div. of Oil, Gas & Mining	3-Triad Center #350 355 West N. Temple Salt Lake City, UT 84180-1203	(801) 538-5340
WY	Deptartment of Environmental Quality, Div. of Land Quality	Equality State Bank Building 3rd Floor 122 W. 125th St. Cheyenne, WY 82002	(307) 777-7756

EASTERN STATE REGULATORY AGENCIES

AL	Alabama Surface Mining Commission	Box 2390 Jasper, AL 35502-2390	(205) 221-4130
GA	Surface Mined Land Reclamation Program	P.O. Box 233 Macon, GA 31202	(912) 744-3346
KY	Natural Resources & Environmental Protection Cabinet	6th Floor Capitol Plaza Tower Frankfort, KY 40601	(502) 564-2141

and:	Department of Surface Mining Reclamation & Enforcement	3rd Floor Capitol Plaza Tower Frankfort, KY 40601	(502) 564-6940
MD	Energy Administrator	Tawes State Office Building 580 Taylor Avenue Annapolis, MD 21401	(301) 269-2788
and:	Dept. of Natural Resources, Bureau of Mines	69 Hill Street Frostburg, MD 21532	(301) 689-4136
MI	Dept. of Natural Resources	Stevens T. Mason Bldg. P.O. Box 30028 Lansing, MI 48909	(517) 373-2329
MS	Dept. of Natural Resources	2380 Hwy. 80 West Jackson, MS 39216	(601) 961-5099
and:	Bureau of Geology Div. of Mining & Reclamtion	2525 Northwest St. P.O. Box 5348 Jackson, MS 39216	(601) 354-6228
OH	Dept. of Natural Resources	1885 Fountain Square Bldg. D-3 Columbus, OH 43224	(614) 265-1092
PA	Department of Environmental Resources	P.O. Box 2063 Harrisburg, PA 17120	(717) 787-2267
TN	Bureau of Environment Dept. of Health & Environment	T.E.R.R.A. Bldg. 150 9th Ave. North Nashville, TN 37203	(615) 741-3657
VA	Dept. of Mines, Minerals & Energy	2201 W. Board St. Richmond, VA 23220	(804) 257-0330
WV	Dept. of Energy	1615 Washington St. E. Charleston, WV 25311	(304) 348-3500

APPENDIX 'A'

REGRESSION ANALYSIS

(i) Notes on data collection.

(ii) Notes on data recording.

(iii) OSMRE Approved regression analysis program: LISTING.

(iv) OSMRE Approved regression analysis program: USE.

(v) OSMRE Approved regression analysis program: EXAMPLE.

(vi) Notes on Vibra-Tech regression analysis program.

(vii) Example of V-T regression analysis:
(same data as in (v) above)

(viii) Example of regression curves, and "blaster aid" curves
(V-T Analysis, same data)

(ix) V-T regression analysis calculator program.

APPENDIX 'A': REGRESSION ANALYSIS

(i) NOTES ON DATA COLLECTION:

In addition to the rules outlined in Chapter 9, pages 77-78, the fundamental principle in good data collection is simple common sense. The supporting principle is consistency. When it is remembered that these are basically exercises in comparisons, then these fundamentals become obvious.

To commence any analysis exercise of this type, the area in which the analysis is to be performed should be documented and studied. All the examples in this Appendix will be based on the fictitious Blackrock Coal Company, of Blackrock, Wyorado, and the studies and analyses based on their #2 Pit Overburden will be typical of a small surface mine operation in the West, but, of course, will also be fictitious.

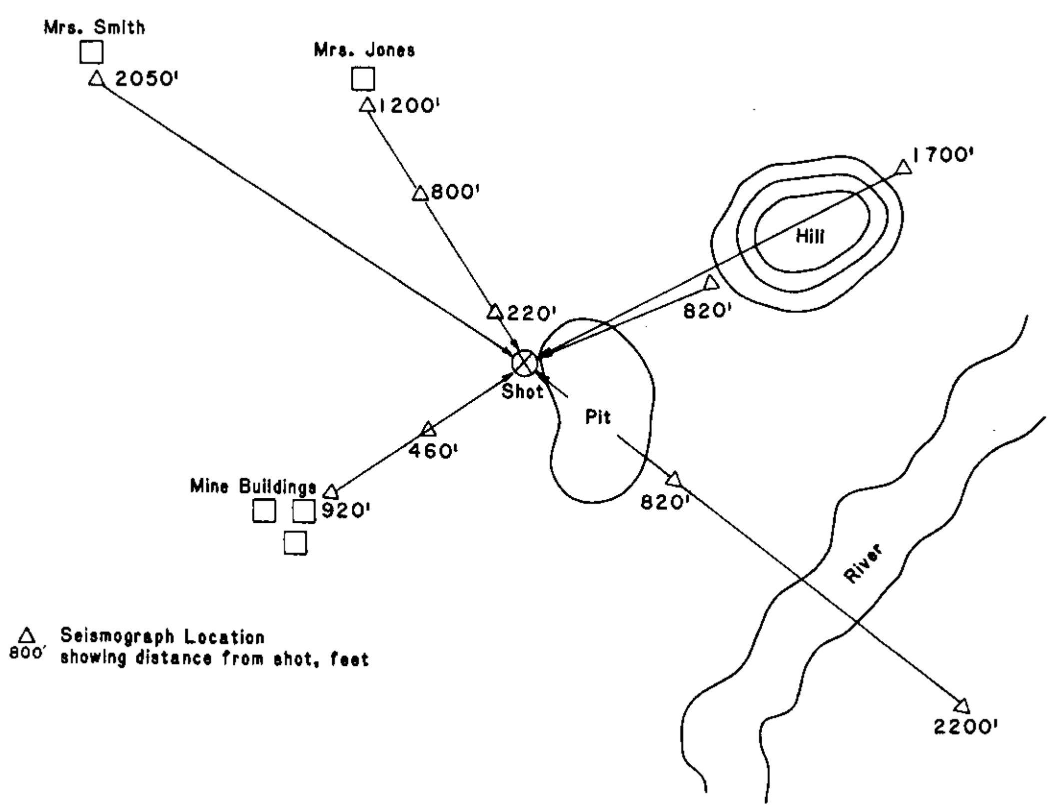


Figure 56.
"Eaglefeather Mine, Blackrock, Wyorado."

Appendix 'A': Regression analysis

Let it be assumed that the area surrounding the Blackrock #2 Pit be as shown in Figure 56, on the previous page. The pit itself is some 1000 ft. northeast of the mine complex, and the major terrain features are a hill, 500 ft. high, 1000 ft. northeast of the pit, and a river 1600 ft. southeast of it. Seismograph readings have been taken at all of the marked seismograph locations, for both coal and overburden shots, and the results have not seemed to have brought any real help. The attenuation formula developed did not offer any real advantage over the scaled distance rule - or over the DuPont Handbook formula, and the co-efficient of determination - the "goodness of fit" - at a disappointing .56 looked more like a "badness of fit".

This is a situation that does not encourage much enthusiasm about the accuracy of statistical prediction techniques!

First: COAL and OVERBURDEN results (as well as PRE-SPLIT results) must be separated, and analyzed separately.

Second: Look again at Figure 56.

There may be valid reasons why it was desirable to take measurements behind the hill 1700 ft. from the blast, and across the river 2200 ft. from it. The possibility of complaints at those sites is one very good reason to monitor. The facts that the open pit and a hill lie between one site and the blast, and the open pit and a river lie between the other site and the blast are also very good reasons why those results should be excluded from any regression analysis.

In fact, both seismograph positions across the pit from the shot, at 820 ft. distance, are also less than desirable. In this instance, the area generally behind the blasting location should again be separated from the area in front and across the pit, unless of course consistent results indicate that the vibration attenuation characteristics are similar in the two areas. This is unlikely.

If the western half of the area is selected for the study, it can then be recognized that:

(a) the topography and geology are generally similar;

(b) no vibration-absorbing features: pit, hill, or river, are present to cause untypically low results; and

(c) the remainder of the area contains all significant or critical structures: the mine complex itself, and both the Smith and Jones residences, where complaints have originated in the past.

Allowing that, for the sake of convenience, all overburden blasting will take place in the marked 'shot' area, and that the explosive charge weight per delay will vary from 50-1500 lbs., if the data collected is confined to this general area, and if the rules set down in Chapter 9 are followed, then the results will be much more encouraging.

A new vibration prediction analysis may now be performed:

(ii) NOTES ON DATA RECORDING:

Again, reference should be made to Chapter 9, and also to Chapter 12. It has been already agreed that distances and explosive charge weights will be measured and not guessed. Asking some blasters for exact, measured distances and charge weights is often something of a problem, and will give an indication of how seldom these two vital measurements are known, for certain. It is essential however that the number of unknown factors be reduced as much as possible; hence, NO GUESSING!

What is the goal of the analysis? If it is to determine the suitability of a low scaled distance, or to predict a velocity at a low scaled distance, then <u>some</u> of the data at least must be measured at or below these <u>low</u> scaled distances. Although the likelihood of real damage at a high scaled distance - say 100 or more - is virtually non-existent, it is a fact that householders can and do complain at those high scaled distances. If damage complaints are to be countered by reference to, and prediction made at high scaled distances, then <u>some</u> of the data, at least, must be measured at or above these <u>high</u> scaled distances. Even if the vibration traces are flat, some recordings should be made at high scaled distances. This points again to the major disadvantage of the seismically triggered unit. It is very convenient and sometimes essential when measuring close in to the blast, at a low scaled distance, but at a high scaled distance it may not record at all! Under complaint situations, a flat trace, made at the time the shot was fired, is much better than no record at all, even when it is noted that the instrument did not trigger.

Again, if it is desired to predict into a high particle velocity range, some at least of the data should be recorded at, or very near to, the highest velocity desired. Maximum charge weights per delay for reliable prediction should not greatly exceed charge weights in the gathered data, as also minimum distances predicted should not be very much less than the actual closest distances at which vibrations were measured. While it is recognized that the fundamental numerical operator in this is the non-dimensional scaled distance, and as such it <u>should</u> apply to <u>any</u> distance or charge weight, nevertheless large excursions from experimentally gathered distances or charge weights imply significantly different blasthole diameters. Significantly altered shot geometry can have an effect on the vibration levels (see Chapter 3, page 22, Control of Adverse Effects). To this extent, therefore, care and common sense must be exercised not to extrapolate too far beyond the limits of the gathered data.

In accordance with all of the foregoing principles, therefore, the vibration data collection exercise has been carried out, and the Blackrock Coal Company finds that it is in possession of 31 good data points.

The following computer programs will perform regression analyses on this data, first using the OSMRE approved program, designed specifically to satisfy the requirements of the Modified Scaled Distance Formula regulation. The same data will also be processed using Vibra-Tech Engineers' simpler general purpose regression program, and comparisons and comments made on the derived output. Both programs, incidentally, produce identical formulas and predictions.

For those without easy access to a computer, these calculations are still possible using a programmable hand calculator. A typical regression analysis program that will run on a Ti 59 calculator is also included in this Appendix. Although the input is directly in Scaled Distance versus Velocity (Scaled Distances have to be calculated separately prior to running the program, as opposed to entering distance, charge weight and velocity), the output is precisely the same as the computer programs. Any differences that might be noted between any of these programs will be very small indeed, and will be due simply to variations in the accuracies of the operating systems. As such, they may be ignored. Any significant difference will be found to be due to an error in program or data entry.

Appx. 'A': OSMRE program listing

```
10 REM **********************************************************************
20 REM
30 REM     PROGRAM "BLAST"
40 REM     Written By: Gregory L. Morlock
50 REM                 U.S. Office of Surface Mining
60 REM                 Western Technical Center
70 REM                 1020 15th St.
80 REM                 Denver, CO 80202
90 REM
100 REM
110 REM       This program performs a linear regression analysis of blast
120 REM       data and will predict peak particle velocity at a given
130 REM       distance from a blast.  Also, based upon your data, this program
140 REM       will produce a table showing the maximum charge-per-delay for
150 REM       various distances.  Three items of input data are needed per
160 REM       shot; the distance from the shot, the maximum weight of explosive
170 REM       per delay, and the measured maximum peak particle velocity.
180 REM       This program will not extrapolate peak velocities. If you need to
190 REM       know particle velocities for a certain scaled distance, you must
200 REM       have measured data above and below that scaled distance.
210 REM       The program also provides information about the 'goodness of fit'
220 REM       of the collected data.  This program also provides a
230 REM       graphical output to the screen. A minimum of 30 data pairs are
240 REM       needed for a reliable analysis (assuming that good data collection
250 REM       techniques have been adhered to) but, for non-critical purposes it
260 REM       is possible to derive results from a lesser number.
270 REM
280 REM **********************************************************************
290 KEY OFF
300 OPTION BASE 1
310 SCREEN 0: WIDTH 80: COLOR 15,1,1
320 DIM D(99),W(99),VELOC(99),DISCRP$(3),X(99),Y(99)
330 REM
340 IFLG%=0
350 CLS
360 PRINT" O S M   B L A S T   V I B R A T I O N   R E G R E S S I O N   A N A L
 Y S I S"
370 PRINT
380 REM  Choose data input method
390 PRINT"Do you want to: 1. Read data from a disk file?"
400 PRINT"                2. Update data or edit from a disk file?"
410 PRINT"                3. List files on disk?"
420 PRINT"                4. Input new data?"
430 ON ERROR GOTO 390
440 INPUT "[Default: 4] ";ANS1%
450 ON ERROR GOTO 0
460 REM
470 IF ANS1%<0 OR ANS1%>4 THEN PRINT: PRINT"?--Invalid entry. Re-enter.":
GOTO 390
480 ON ANS1% GOTO 500,550,610,690
490 GOTO 690
500 PRINT
510 INPUT "Enter file name for data file--> ",FILE$
520 IF FILE$="" GOTO 500
530 GOSUB 1090 'Readit subroutine
540 GOTO 800
550 PRINT
560 INPUT "Enter file name for data file--> ",FILE$
570 IF FILE$="" GOTO 550
580 GOSUB 1090 'Readit subroutine
```

```
590 GOSUB 1540 'Manual subroutine
600 GOTO 800
610 CLS
620 FILES
630 INPUT "Press <ENTER> to continue",ANS$
640 PRINT
650 GOTO 390
660 REM
670 REM Default call for manual data input and optional save.
680 REM
690 N%=0
700 PRINT
710 PRINT "Enter vibration study description - 3 lines -":PRINT" Should include
DATE, NAME & LOCATION"
720 PRINT
730 FOR I%=1 TO 3: LINE INPUT DISCRP$(I%)
740 NEXT I%
750 REM
760 GOSUB 1540 'Manual subroutine
770 REM
780 REM  Start Calculations
790 REM
800 SDMAX=D(1)/SQR(ABS(W(1)))
810 SDMIN=SDMAX
820 REM
830 DMAX=0: EMAX=0
840 FOR I%=1 TO N%
850 IF D(I%)>DMAX THEN DMAX=D(I%)
860 IF W(I%)>EMAX THEN EMAX=W(I%)
870 NEXT I%
880 FOR I%=1 TO N%
890  DS=D(I%)/SQR(ABS(W(I%)))
900  X(I%)=LOG(DS)
910  Y(I%)=LOG(VELOC(I%))
920  REM
930  IF DS<SDMIN THEN SDMIN=DS
940  IF DS>SDMAX THEN SDMAX=DS
950 NEXT I%
960 REM
970 GOSUB 2450 'Regres subroutine
980 REM
990 GOSUB 2900 'Outpt subroutine
1000 REM
1010 SYSTEM
1020 END
1030 REM**********************************************************************
1040 REM SUBROUTINE READIT
1050 REM
1060 REM  This subroutine will read a previously created data file from disk.
1070 REM  The data should consist of three 80 character description lines
1080 REM  followed by the data (distance, charge, velocity).
1090 PRINT
1100 PRINT"    - Reading file. Please wait -"
1110 ON ERROR GOTO 1430
1120 OPEN FILE$ FOR INPUT AS #1
1130 ON ERROR GOTO 1380
1140 REM
1150 FOR I%=1 TO 3
1160 LINE INPUT #1,DISCRP$(I%)
1170 NEXT I%
1180 REM
1190 N%=0
```

```
1200 REM
1210 REM Read loop
1220 REM
1230 ON ERROR GOTO 1380
1240 IF EOF(1) THEN GOTO 1310
1250 N%=N%+1
1260 INPUT#1,D(N%),W(N%),VELOC(N%)
1270 GOTO 1240
1280 REM
1290 REM  End loop
1300 REM
1310 ON ERROR GOTO 0
1320 CLS
1330 REM
1340 GOTO 1480
1350 REM
1360 REM Error section
1370 REM
1380 RESUME 1390
1390 PRINT
1400 PRINT"---Error while trying to read ";FILE$;" ---"
1410 PRINT:INPUT "Enter another file name for data--> ",FILE$
1420 GOTO 1090
1430 RESUME 1440
1440 PRINT
1450 PRINT"---Error while trying to open ";FILE$;" ---"
1460 PRINT:INPUT "Enter another file name for data--> ",FILE$
1470 GOTO 1090
1480 CLOSE #1
1490 RETURN
1500 REM*****************************************************************
1510 REM SUBROUTINE MANUAL
1520 REM
1530 REM This routine will allow the user to manually input data.
1540 REM Start of data input
1550 REM
1560 PRINT
1570 PRINT "DATA INPUT SECTION."
1580 PRINT
1590 PRINT "Data must be entered in consistent units:"
1600 PRINT "It is usual for distance to be in `feet',"
1610 PRINT "charge-per-delay to be in `pounds', and peak"
1620 PRINT "particle velocity to be in `inches-per-second.'"
1630 PRINT
1640 PRINT "Press <ENTER> key alone after entering all data."
1650 REM
1660 REM Data input loop
1670 REM
1680 REM#################################################################
1690 N%=N%+1
1700 PRINT
1710 PRINT USING "Enter distance No. ##------------------->";N%;
1720 INPUT " ",D(N%)
1730 IF D(N%)=0 THEN GOTO 1860
1740 PRINT USING "Enter maximum charge-per-delay No. ##-->";N%;
1750 INPUT " ",W(N%)
1760 IF W(N%)=0 THEN GOTO 1860
1770 PRINT USING "Enter particle velocity No. ##---------->";N%;
1780 INPUT " ",VELOC(N%)
1790 IF VELOC(N%)=0 THEN GOTO 1860
1800 GOTO 1690
1810 REM
```

```
1820 REM End of data input loop
1830 REM
1840 REM##########################################################################
1850 REM
1860 N%=N%-1
1870 IF N%<30 THEN PRINT:PRINT "--WARNING-- A valid analysis requires 30 or more
 data pairs"
1880 REM
1890 REM Give user a chance to edit input data
1900 GOSUB 3510   Edit subroutine
1910 REM
1920 PRINT
1930 INPUT "Do you wish to save this data to disk? [Default: Y]";ANS$
1940 IF ANS$="" THEN GOTO 1980
1950 IF LEFT$(ANS$,1)="N" OR LEFT$(ANS$,1)="n" THEN RETURN
1960 IF LEFT$(ANS$,1)<>"Y" AND LEFT$(ANS$,1)<>"y" THEN PRINT:PRINT"?---Invalid i
nput. Re-enter.": GOTO 1920
1970 REM
1980 PRINT
1990 PRINT "You can write a new file or overwrite an old file."
2000 INPUT "Enter data file name--> ",FILE$
2010 IF FILE$="" THEN GOTO 1980
2020 ON ERROR GOTO 2060
2030 OPEN FILE$ FOR OUTPUT AS #1
2040 GOTO 2100
2050 REM Error recovery
2060 PRINT
2070 PRINT "---Error--could not open ";FILE$
2080 GOTO 1920
2090 REM
2100 ON ERROR GOTO 2310
2110 REM
2120 REM Write data to file
2130 REM
2140 PRINT
2150 PRINT " - Writing file.  Please Wait -"
2160 FOR I%=1 TO 3
2170  PRINT#1, USING "&";DISCRP$(I%)
2180 NEXT I%
2190 REM
2200 FOR I%=1 TO N%
2210  PRINT#1,USING "########.# #######.# #####.####";D(I%),W(I%),VELOC(I%)
2220 NEXT I%
2230 REM
2240 CLOSE #1
2250 ON ERROR GOTO 0
2260 CLS
2270 GOTO 2350
2280 REM
2290 REM Error section
2300 REM
2310 PRINT
2320 PRINT "---An error occurred while writing the data file."
2330 STOP
2340 REM
2350 RETURN
2360 REM*********************************************************************
2370 REM SUBROUTINE REGRES
2380 REM
2390 REM This subroutine performs a standard linear regression analysis.
2400 REM It finds the line Y=B0+B1X from a scattered data set.
2410 REM Input consists of the scattered data arrays X and Y and N, the
```

```
2420 REM number of data pairs.  This subroutine outputs: B0-the Y intercept;
2430 REM B1-the slope; S-the sample standard deviation; Xbar-the mean of the
2440 REM X's; SSX-the sum of the squares of X; and r-the coefficient of corr.
2450 SUMX=0
2460 SUMY=0
2470 SUMX2=0
2480 SUMXY=0
2490 SUMY2=0
2500 REM
2510 REM Calculate the sums used for calculating the sums of squares
2520 REM
2530 FOR I%=1 TO N%
2540  SUMX=SUMX+X(I%)
2550  SUMY=SUMY+Y(I%)
2560  SUMX2=SUMX2+X(I%)^2
2570  SUMY2=SUMY2+Y(I%)^2
2580  SUMXY=SUMXY+X(I%)*Y(I%)
2590 NEXT I%
2600 REM
2610 REM Calculate the sums of squares
2620 REM
2630 XN=N%
2640 IF N%<3 THEN PRINT:PRINT"---Error--- Must have more data!":STOP
2650 REM
2660 SSX=SUMX2-SUMX^2/XN
2670 SSY=SUMY2-SUMY^2/XN
2680 SSXY=SUMXY-SUMX*SUMY/XN
2690 REM
2700 REM Calculate the means
2710 REM
2720 YBAR=SUMY/XN
2730 XBAR=SUMX/XN
2740 REM
2750 REM Calculate the coefficients
2760 REM
2770 B1=SSXY/SSX
2780 B0=YBAR-B1*XBAR
2790 REM
2800 REM Calculate the sample standard deviation and the coefficient of corr.
2810 REM
2820 S=SQR((SSY-B1*SSXY)/XN)
2830 R=SSXY/SQR(SSX*SSY)
2840 REM
2850 RETURN
2860 REM*********************************************************************
2870 REM SUBROUTINE OUTPT
2880 REM This subroutine provides the output choices.
2890 REM
2900 CLS
2910 R2=R^2
2920 Q=EXP(B0+2*S)
2930 PRINT"O U T P U T   S E C T I O N"
2940 PRINT
2950 PRINT USING "The 95% confidence level equation is: PV=####.###(Ds)^##.##";Q
;B1
2960 PRINT USING "The coefficient of determination (r^2 - 'goodness of fit') is:
 #.##";R2
2970 PRINT USING "This analysis has ### data pairs.";N%
2980 IF N%<30 THEN PRINT "--WARNING-- A valid analysis requires 30 or more pairs
."
2990 REM
3000 REM Find the applicable scaled distances
```

```
3010 REM PV for 0 to 300 ft
3020 PV=1.25
3030 GOSUB 4640 'Solve subroutine
3040 IF DS1<SDMIN THEN PRINT:PRINT"---Error---":PRINT"You do not have data with
a low enough scaled distance to predict for a":PRINT" distance for 0 to 300 ft."
:GOTO 3110
3050 IF DS1>SDMAX THEN PRINT:PRINT"---Error---":PRINT"You do not have data with
a high enough scaled distance to predict for a":PRINT" distance for 0 to 300 ft.
":GOTO 3110
3060 PRINT
3070 PRINT USING "The scaled distance for 0 to 300 ft. is: ###.##";DS1
3080 REM
3090 REM PV for 301 to 5000 ft
3100 REM
3110 PV=1!
3120 GOSUB 4640 'Solve subroutine
3130 IF DS1<SDMIN THEN PRINT:PRINT"---Error---":PRINT"You do not have data with
a low enough scaled distance to predict for a":PRINT" distance for 300 to 5000 f
t.":GOTO 3200
3140 IF DS1>SDMAX THEN PRINT:PRINT"---Error---":PRINT"You do not have data with
a high enough scaled distance to predict for a":PRINT" distance for 300 to 5000
ft.":GOTO 3200
3150 PRINT
3160 PRINT USING "The scaled distance for 301 ft. to 5000 ft. is: ###.##";DS1
3170 REM
3180 REM PV for 5001 ft and beyond
3190 REM
3200 PV=.75
3210 GOSUB 4640 'Solve subroutine
3220 IF DS1<SDMIN THEN PRINT:PRINT"---Error---":PRINT"You do not have data with
a low enough scaled distance to predict for a":PRINT" distance for 5000 ft and b
eyond.":GOTO 3290
3230 IF DS1>SDMAX THEN PRINT:PRINT"---Error---":PRINT"You do not have data with
a high enough scaled distance to predict for a":PRINT" distance for 5000 ft and
beyond.":GOTO 3290
3240 PRINT
3250 PRINT USING "The scaled distance for 5001 ft. and beyond is: ###.##";DS1
3260 REM
3270 REM Ask for options
3280 REM
3290 PRINT
3300 PRINT"Do you want: 1. Calculated charge per delay for given distance?"
3310 PRINT"             2. Printed table of distance vs. charge per delay and su
mmary?"
3320 PRINT"             3. Scaled Distance for any maximum velocity?"
3330 PRINT"             4. Maximum velocity for any Scaled Distance?"
3340 PRINT"             5. Plot of data and 95% confidence level line?"
3350 PRINT"             6. Quit?"
3360 INPUT "[Default: 6]";ANS1%
3370 IF ANS1%=0 THEN GOTO 3450
3380 REM
3390 IF ANS1%<1 OR ANS1%>6 THEN PRINT:PRINT"?--Invalid input.  Re-enter.":     G
OTO 3290
3400 IF ANS1%=1 THEN GOSUB 4750: CLS:GOTO 3290
3410 IF ANS1%=2 THEN GOSUB 5200: CLS:GOTO 3290
3420 IF ANS1%=3 THEN GOSUB 6480: CLS:GOTO 3290
3430 IF ANS1%=4 THEN GOSUB 6810: CLS:GOTO 3290
3440 IF ANS1%=5 THEN GOSUB 7210: CLS:GOTO 3290
3450 RETURN
3460 REM*****************************************************************
3470 REM SUBROUTINE EDIT
3480 REM This subroutine will allow the editing and printout of input data
```

```
3490 REM Printout section
3500 REM
3510 PRINT
3520 INPUT "Do you want a print-out of the input data? [Default: N] ";ANS$
3530 IF ANS$="" THEN GOTO 3850
3540 IF LEFT$(ANS$,1)="N" OR LEFT$(ANS$,1)="n" THEN GOTO 3850
3550 IF LEFT$(ANS$,1)<>"Y" AND LEFT$(ANS$,1)<>"y" THEN PRINT:PRINT"?--Invalid in
put.  Re-enter.": GOTO 3510
3560 REM
3570 PRINT
3580 PRINT"     --  Please Wait, Writing to Printer  --"
3590 REM
3600 IPAGE%=0
3610 NCOUNT%=0
3620 REM
3630 IPAGE%=IPAGE%+1
3640 LPRINT CHR$(12); : LPRINT"Input data summary for:": LPRINT
3650 FOR I%=1 TO 3
3660  LPRINT DISCRP$(I%)
3670 NEXT I%
3680 LPRINT
3690 LPRINT USING "NOTE: Scaled Distance for reference only.
      Page,##";IPAGE%: LPRINT
3700 LPRINT "    Line No.      Distance/ft.      Charge/lb.    Peak Velocity/ips
Scaled Dist.*"
3710 REM
3720 ICOUNT%=0
3730 REM
3740 ICOUNT%=ICOUNT%+1
3750 IF ICOUNT%>50 THEN GOTO 3630
3760 NCOUNT%=NCOUNT%+1
3770 DST=D(NCOUNT%)/SQR(ABS(W(NCOUNT%)))
3780 LPRINT USING "         ###        ##########   ##########      ###########.##
      ########.#";NCOUNT%;D(NCOUNT%);W(NCOUNT%);VELOC(NCOUNT%);DST
3790 REM
3800 IF NCOUNT%<N% GOTO 3740
3810 IFLG%=1
3820 REM
3830 REM Screen printout
3840 REM
3850 NCOUNT%=0
3860 CLS
3870 PRINT DISCRP$(1)
3880 PRINT DISCRP$(2)
3890 PRINT DISCRP$(3)
3900 PRINT
3910 PRINT "* Note: Scaled Distance for reference only."
3920 PRINT "    Line No.      Distance/ft.      Charge/lb.    Peak Velocity/ips  S
caled Dist.*"
3930 PRINT
3940 REM
3950 ICOUNT%=0
3960 REM
3970 ICOUNT%=ICOUNT%+1
3980 IF ICOUNT%<16 THEN GOTO 4050
3990 INPUT "Do you want to see more data? [Default: Y]";ANS$
4000 IF ANS$="" THEN GOTO 3860
4010 IF LEFT$(ANS$,1)="N" OR LEFT$(ANS$,1)="n" THEN GOTO 4120
4020 IF LEFT$(ANS$,1)<>"Y" AND LEFT$(ANS$,1)<>"y" THEN PRINT:PRINT"?--Invalid in
put.  Re-enter.": GOTO 3990
4030 GOTO 3860
4040 REM
```

```
4050 NCOUNT%=NCOUNT%+1
4060 DST=D(NCOUNT%)/SQR(ABS(W(NCOUNT%)))
4070 PRINT USING "     ###        ##########    ##########      ###########.##
    ########.#";NCOUNT%;D(NCOUNT%);W(NCOUNT%);VELOC(NCOUNT%);DST
4080 IF NCOUNT%<N% THEN GOTO 3970
4090 REM
4100 REM Editing section
4110 REM
4120 PRINT
4130 PRINT"Do you wish to: 1. Edit vibration study description?"
4140 PRINT"                2. Edit data?"
4150 PRINT"                3. Re-print data?"
4160 PRINT"                4. Quit editing?"
4170 INPUT "[Default: 4] ";ANS1%
4180 IF ANS1%=0 THEN GOTO 4260
4190 REM
4200 IF ANS1%<1 OR ANS1%>4 THEN PRINT:PRINT"?--Invalid response.  Re-enter":   G
OTO 4120
4210 IF ANS1%=4 THEN GOTO 4260
4220 IF ANS1%=3 THEN GOTO 3510
4230 IF ANS1%=2 THEN GOSUB 4300: GOTO 4120 'Edit data
4240 IF ANS1%=1 THEN GOSUB 4490: GOTO 4120 'Edit description
4250 REM
4260 RETURN
4270 REM*************************************************************************
4280 REM EDIT DATA
4290 REM
4300 PRINT
4310 INPUT "Enter line number to edit, press <ENTER> to quit --> ",NED%
4320 IF NED%=0 THEN GOTO 4450
4330 IF NED%<1 OR NED%>N% THEN PRINT:PRINT"?---N out of range.  Re-enter.":
 GOTO 4300
4340 PRINT
4350 PRINT USING "Enter distance No. ## ------------------>";NED%;
4360 INPUT " ",D(NED%)
4370 IF D(NED%)=0 THEN GOTO 4340
4380 PRINT USING "Enter maximum charge-per-delay No. ## -->";NED%;
4390 INPUT " ",W(NED%)
4400 IF W(NED%)=0 THEN GOTO 4380
4410 PRINT USING "Enter particle velocity No. ## --------->";NED%;
4420 INPUT " ",VELOC(NED%)
4430 IF VELOC(NED%)=0 THEN GOTO 4410
4440 GOTO 4300
4450 RETURN
4460 REM************************************************************************
4470 REM EDIT DESCRIPTION
4480 REM
4490 PRINT
4500 PRINT "The current description is:": PRINT
4510 PRINT DISCRP$(1)
4520 PRINT DISCRP$(2)
4530 PRINT DISCRP$(3)
4540 PRINT:PRINT "Input 3 new lines of description. (Follow each line by <ENTER>
 )"
4550 FOR I%=1 TO 3
4560  LINE INPUT DISCRP$(I%)
4570 NEXT I%
4580 RETURN
4590 REM ***********************************************************************
4600 REM SOLVE SUBROUTINE
4610 REM This subroutine will find the scaled distance for a given particle
4620 REM velocity.  The scaled distance approximated by intersecting the
```

```
4630 REM particle velocity with the prediction line plus 2 standard devs.
4640 IF N%<3 THEN PRINT:PRINT "---Insufficient data for analysis: MUST have at l
east 3 pairs---":STOP
4650 IF N%>99 THEN PRINT:PRINT"---Too many data points.---":PRINT"Data arrays ha
ve been overwritten":STOP
4660 REM
4670 DS1=EXP((LOG(PV)-B0-2*S)/B1)
4680 REM
4690 RETURN
4700 REM*********************************************************************
4710 REM SUBROUTINE INTRAT
4720 REM This subroutine allows the user to interactively try different
4730 REM blasting scenarios and have the results printed to the screen.
4740 REM
4750 PRINT
4760 INPUT "Enter distance to critical structure. Press <ENTER> to quit--> ",DIS
TAN
4770 IF DISTAN=0 THEN GOTO 5000
4780 IF DISTAN<0 THEN PRINT:PRINT"Error -- Distance must be positive.":  GOTO
4750
4790 REM
4800 REM Find the maximum allowable particle velocity for the given distance.
4810 REM
4820 GOSUB 7140 'DISTAN SUBROUTINE
4830 REM
4840 REM Find the scaled distance for the maximum particle velocity.
4850 REM
4860 GOSUB 4640 'Solve Subroutine
4870 REM
4880 REM Check Scaled distance range
4890 REM
4900 IF DS1<SDMIN THEN GOSUB 5020: GOTO 4750
4910 IF DS1>SDMAX THEN GOSUB 5090: GOTO 4750
4920 REM
4930 REM Output results
4940 REM
4950 W=(DISTAN/DS1)^2
4960 PRINT
4970 PRINT USING "At a distance of ##### ft., you may use a";DISTAN
4980 PRINT USING "maximum charge of ###### lbs./delay";W
4990 GOTO 4750
5000 RETURN
5010 REM ***********ERROR OUTPUT********
5020 PRINT
5030 PRINT"---Error---"
5040 PRINT USING "The lowest scaled distance for your data is ###.##";SDMIN
5050 PRINT "You do not have data with a low enough scaled distance"
5060 PRINT USING "to predict for a distance of ##### ft.";DISTAN
5070 RETURN
5080 REM***********ERROR OUTPUT********
5090 PRINT
5100 PRINT"---Error---"
5110 PRINT USING "The highest scaled distance for your data is ###.##";SDMAX
5120 PRINT "You do not have data with a high enough scaled distance"
5130 PRINT USING "to predict for a distance of ##### ft.";DISTAN
5140 RETURN
5150 REM*********************************************************************
5160 REM SUBROUTINE TABLE
5170 REM This subroutine provides a table of maximum charge/delay for
5180 REM different distances
5190 REM
5200 PRINT
```

```
5210 PRINT "  -   Printing table.  Please wait.  -"
5220 REM
5230 REM Output for 0-300 ft
5240 REM
5250 PV=1.25
5260 GOSUB 4640 'SUBROUTINE SOLVE
5270 IFLG%=1
5280 REM
5290 LPRINT CHR$(12);
5300 LPRINT "OSM Charge Weight per Delay Table for 0 - 300 ft"
5310 LPRINT USING "based on ## data pairs for:";N%
5320 LPRINT DISCRP$(1)
5330 LPRINT DISCRP$(2)
5340 LPRINT DISCRP$(3)
5350 LPRINT
5360 LPRINT USING "The scaled distance for this distance range is ###.##";DS1
5370 LPRINT
5380 LPRINT "     Dist(ft)  Charge(lb)     Dist(ft)  Charge(lb)     Dist(ft)  Ch
arge(lb)"
5390 REM
5400 IF DS1<SDMIN THEN GOSUB 6320: GOTO 5570
5410 IF DS1>SDMAX THEN GOSUB 6380: GOTO 5570
5420 REM
5430 FOR I%=50 TO 132 STEP 2
5440  D1=I%
5450  D2=D1+84
5460  D3=D1+168
5470  C1=(D1/DS1)^2
5480  C2=(D2/DS1)^2
5490  C3=(D3/DS1)^2
5500  LPRINT USING "      #####  -  ######         #####  -  ######         ####
#  -  ######";D1;C1;D2;C2;D3;C3
5510 NEXT I%
5520 LPRINT
5530 IF N%<30 THEN : LPRINT"---WARNING--- A valid analysis requires 30 or more d
ata pairs."
5540 REM
5550 REM Output for 301 to 5000 ft
5560 REM
5570 PV=1!
5580 GOSUB 4640 'SUBROUTINE SOLVE
5590 REM
5600 IF C3=0 GOTO 3290
5610 IF D3=0 GOTO 3290
5620 LPRINT CHR$(12);
5630 LPRINT "OSM Charge Weight per Delay Table for 301 - 5000 ft"
5640 LPRINT USING "based on ## data pairs for:";N%
5650 LPRINT DISCRP$(1)
5660 LPRINT DISCRP$(2)
5670 LPRINT DISCRP$(3)
5680 LPRINT
5690 LPRINT USING "The scaled distance for this distance range is ###.##";DS1
5700 LPRINT
5710 LPRINT "     Dist(ft)  Charge(lb)     Dist(ft)  Charge(lb)     Dist(ft)  Ch
arge(lb)"
5720 REM
5730 IF DS1<SDMIN THEN GOSUB 6320: GOTO 5960
5740 IF DS1>SDMAX THEN GOSUB 6380: GOTO 5960
5750 REM
5760 FOR I%=350 TO 1850 STEP 50
5770  D1=I%
5780  D2=D1+1550
```

```
5790  D3=D1+3100
5800  C1=(D1/DS1)^2
5810  C2=(D2/DS1)^2
5820  C3=(D3/DS1)^2
5830  LPRINT USING "      #####  -  ######         #####  -  ######         ####
#  -  ######";D1;C1;D2;C2;D3;C3
5840 NEXT I%
5850 REM
5860 D1=5000!
5870 C1=(D1/DS1)^2
5880 LPRINT USING "                                                          #####
  -  ######";D1;C1
5890 LPRINT
5900 LPRINT"Although the above charge weights-per-delay are authorized under the
"
5910 LPRINT"regulations, they may exceed, or greatly exceed, practical limitatio
ns."
5920 IF N%<30 THEN : LPRINT"---WARNING--- A valid analysis requires 30 or more d
ata pairs."
5930 REM
5940 REM Output for 5001 ft and beyond
5950 REM
5960 PV=.75
5970 GOSUB 4640 'SUBROUTINE SOLVE
5980 REM
5990 IF C3=0 GOTO 3290
6000 IF D3=0 GOTO 3290
6010 LPRINT CHR$(12);
6020 LPRINT "OSM Charge Weight per Delay Table for 5001 ft and beyond"
6030 LPRINT USING "based on ## data pairs for:";N%
6040 LPRINT DISCRP$(1)
6050 LPRINT DISCRP$(2)
6060 LPRINT DISCRP$(3)
6070 LPRINT
6080 LPRINT USING "The scaled distance for this distance range is ###.##";DS1
6090 LPRINT
6100 LPRINT "     Dist(ft)  Charge(lb)     Dist(ft)  Charge(lb)    Dist(ft)  Ch
arge(lb)"
6110 REM
6120 IF DS1<SDMIN THEN GOSUB 6320: GOTO 6310
6130 IF DS1>SDMAX THEN GOSUB 6380: GOTO 6310
6140 REM
6150 FOR I%=5050 TO 7500 STEP 50
6160  D1=I%
6170  D2=D1+2500
6180  D3=D1+5000
6190  C1=(D1/DS1)^2
6200  C2=(D2/DS1)^2
6210  C3=(D3/DS1)^2
6220  LPRINT USING "      #####  -  ######         #####  -  ######         ####
#  -  ######";D1;C1;D2;C2;D3;C3
6230 NEXT I%
6240 LPRINT
6250 LPRINT"Although the above charge weights-per-delay are authorized under the
6260 LPRINT"regulations, they may exceed, or greatly exceed, practical limitatio
ns."
6270 IF N%<30 THEN : LPRINT"---WARNING--- A valid analysis requires 30 or more d
ata pairs."
6280 GOSUB 8350 'END SUBROUTINE
6290 REM*************ERROR OUTPUT*********
6300 CLS
6310 RETURN
```

```
6320 LPRINT
6330 LPRINT"---Error---"
6340 LPRINT USING "The minimum scaled distance for this data, ###.##,";SDMIN
6350 LPRINT"is not low enough to predict for this particle velocity."
6360 RETURN
6370 REM*************ERROR OUTPUT*********
6380 LPRINT
6390 LPRINT"---Error---"
6400 LPRINT USING "The maximum scaled distance for this data, ###.##,";SDMAX
6410 LPRINT"is not high enough to predict for this particle velocity."
6420 RETURN
6430 REM*****************************************************************
6440 REM SUBROUTINE SCALE
6450 REM This subroutine will report the scaled distance for any maximum
6460 REM particle velocity.
6470 REM
6480 PRINT
6490 INPUT "Enter maximum particle velocity. Press <ENTER> to quit.---> ",PV
6500 IF PV=0 THEN GOTO 6640
6510 REM
6520 GOSUB 4640 'SUBROUTINE SOLVE
6530 REM
6540 IF PV<0 THEN PRINT:PRINT"?--Invalid input. Particle velocity must be positi
ve.": GOTO 6480
6550 REM
6560 IF DS1<SDMIN THEN GOSUB 6660: GOTO 6480
6570 IF DS1>SDMAX THEN GOSUB 6720: GOTO 6480
6580 REM
6590 PRINT
6600 PRINT USING "For a maximum particle velocity of ##.## ips";PV
6610 PRINT USING "the scaled distance will be: ###.##";DS1
6620 GOTO 6480
6630 REM
6640 RETURN
6650 REM*************ERROR OUTPUT*********
6660 PRINT
6670 PRINT"---Error---"
6680 PRINT USING "The minimum scaled distance for this data, ###.##,";SDMIN
6690 PRINT"is not low enough to predict for this maximum particle velocity."
6700 RETURN
6710 REM*************ERROR OUTPUT*********
6720 PRINT
6730 PRINT"---Error---"
6740 PRINT USING "The maximum scaled distance for this data, ###.##,";SDMAX
6750 PRINT"is not high enough to predict for this maximum particle velocity."
6760 RETURN
6770 REM*****************************************************************
6780 REM SUBROUTINE VELO
6790 REM This subroutine will report the max. velocity for any scaled distance
6800 REM
6810 PRINT
6820 INPUT "Enter scaled distance. Press <ENTER> to quit.---> ",DS1
6830 IF DS1=0 THEN GOTO 6950
6840 IF DS1<0 THEN PRINT:PRINT"?---Invalid input. Scaled distance must be positi
ve.": GOTO 6810
6850 IF DS1<SDMIN THEN GOSUB 6970: GOTO 6810
6860 IF DS1>SDMAX THEN GOSUB 7030: GOTO 6810
6870 REM
6880 PV=EXP(B0+2*S+B1*LOG(DS1))
6890 REM
6900 PRINT
6910 PRINT USING "For a scaled distance of ###.##,";DS1
```

```
6920 PRINT USING "the maximum particle velocity will be: ##.## ips";PV
6930 REM
6940 GOTO 6810
6950 RETURN
6960 REM************ERROR OUTPUT*********
6970 PRINT
6980 PRINT"---Error---"
6990 PRINT USING "The minimum scaled distance for this data is ###.##.";SDMIN
7000 PRINT "The scaled distance input is too low."
7010 RETURN
7020 REM************ERROR OUTPUT*********
7030 PRINT
7040 PRINT"---Error---"
7050 PRINT USING "The maximum scaled distance for this data is ###.##.";SDMAX
7060 PRINT "The scaled distance input is too high."
7070 RETURN
7080 REM**********************************************************************
7090 REM SUBROUTINE PARTV
7100 REM This subroutine will return the maximum regulatory allowable particle
7110 REM velocity for a given distance.  These velocities are from
7120 REM 30 CFR 816.67, 1984
7130 REM
7140 PV=.75
7150 IF DISTAN<=5000 THEN PV=1!
7160 IF DISTAN<=300 THEN PV=1.25
7170 RETURN
7180 REM**********************************************************************
7190 REM SUBROUTINE GRAPH
7200 REM
7210 LOCATE 18,14:PRINT"Min. Ds = ";SDMIN
7220 CLS
7230 LOCATE 12,5
7240 PRINT"--- Press <ENTER> when you've finished looking at graphics ---"
7250 PRINT:PRINT
7260 INPUT "Do you have a graphics board, or a PCjr? [Default: Y] ";ANS$
7270 IF ANS$="" THEN GOTO 7320
7280 IF LEFT$(ANS$,1)="Y" OR LEFT$(ANS$,1)="y" THEN GOTO 7320
7290 IF LEFT$(ANS$,1)<>"N" AND LEFT$(ANS$,1)<>"n" THEN GOTO 7250
7300 REM Return if no graphics equipment
7310 RETURN
7320 ON ERROR GOTO 7350
7330 GOTO 7410
7340 REM Error section
7350 RESUME 7360
7360 SCREEN 0: WIDTH 80: COLOR 15,1,1: CLS
7370 PRINT:PRINT"---Error---"
7380 PRINT "Check graphics capability"
7390 ON ERROR GOTO 0
7400 RETURN
7410 SCREEN 2:CLS: IF IFLG%=1 THEN LPRINT CHR$(12);
7420 REM draw xy axis and scale for plot
7430 LINE (90,155)-(590,156),1,BF:LINE (90,25)-(92,155),1,BF
7440 LINE (90,156)-(92,158),1,BF
7450 LINE (256,156)-(258,158),1,BF
7460 LINE (422,156)-(424,158),1,BF
7470 LINE (588,156)-(590,158),1,BF
7480 LINE (90,25)-(84,26),1,BF
7490 LINE (90,67)-(84,68),1,BF
7500 LINE (90,108)-(84,109),1,BF
7510 LINE (90,155)-(84,156),1,BF
7520 LOCATE 4,6:PRINT "10.0"
7530 LOCATE 9,7:PRINT "1.0"
```

```
7540 LOCATE 14,8:PRINT ".1"
7550 LOCATE 20,8:PRINT ".01"
7560 LOCATE 21,12:PRINT "1"
7570 LOCATE 21,32:PRINT "10"
7580 LOCATE 21,52:PRINT "100"
7590 LOCATE 21,72:PRINT "1000"
7600 LOCATE 22,35:PRINT "Scaled Distance (Ds)"
7610 LOCATE 23,19:PRINT"Plot of Data and 95% Confidence Level Line"
7620 LOCATE 11,1:PRINT "Particle"
7630 LOCATE 12,1:PRINT "Velocity"
7640 LOCATE 13,3:PRINT"(PV)"
7650 LOCATE 1,1:PRINT USING "&";DISCRP$(1)
7660 LOCATE 2,1:PRINT USING "&";DISCRP$(2)
7670 LOCATE 3,1:PRINT USING "&";DISCRP$(3)
7680 LOCATE 18,14:PRINT USING "Min. Ds = ###.##";SDMIN
7690 LOCATE 19,14:PRINT USING "Max. Ds = ###.##";SDMAX
7700 REM routine to plot scattered data set
7710 FOR I%=1 TO N%
7720  DST=D(I%)/SQR(W(I%))
7730  XX=.43*LOG(DST)
7740  YY=.43*LOG(VELOC(I%))
7750  IF XX>3 GOTO 7820
7760  IF XX<0 GOTO 7820
7770  IF YY>1 GOTO 7820
7780  IF YY<-2 GOTO 7820
7790  XX=500*XX/3+90
7800  YY=155-130*(YY+2)/3
7810  CIRCLE (XX,YY),2
7820 NEXT I%
7830 REM plot of 95% confidence line within data limits
7840 PV=(B0+B1*LOG(SDMIN))+2*S
7850 PV1=(B0+B1*LOG(SDMAX))+2*S
7860 YY=.434294*PV
7870 YY=155-130*(YY+2)/3
7880 Y1=.434294*PV1
7890 Y1=155-130*(Y1+2)/3
7900 XX=.434294*LOG(SDMIN)
7910 XX=90+500*XX/3
7920 X1=.434294*LOG(SDMAX)
7930 X1=90+500*X1/3
7940 LINE (XX,YY)-(X1,Y1)
7950 REM Define data limits as Dashed lines
7960 YMA=YY-8
7970 FOR I%=1 TO 5
7980  LINE (XX-1,YMA)-(XX,YMA+2),1,BF
7990  YMA=YMA+4
8000 NEXT I%
8010 YMA=Y1-8
8020 FOR I%=1 TO 5
8030  LINE (X1-1,YMA)-(X1,YMA+2),1,BF
8040  YMA=YMA+4
8050 NEXT I%
8060 LOCATE 19,35
8070 PRINT "PV = "
8080 LOCATE 19,40:PRINT USING "###.##";Q
8090 LOCATE 19,46:PRINT"*Ds"
8100 LOCATE 18,49:PRINT USING "##.##";B1
8110 REM Solution for scaled distance for 1.25, 1, and .75 IPS
8120 PV=1.25
8130 GOSUB 4640 'SOLVE SUBROUTINE
8140 IF DS1<SDMIN OR DS1>SDMAX THEN DS1=0
8150 SF125=DS1
```

```
8160 PV=1!
8170 GOSUB 4640 'SOLVE SUBROUTINE
8180 IF DS1<SDMIN OR DS1>SDMAX THEN DS1=0
8190 SF1=DS1
8200 PV=.75
8210 GOSUB 4640 'SOLVE SUBROUTINE
8220 IF DS1<SDMIN OR DS1>SDMAX THEN DS1=0
8230 SF75=DS1
8240 LOCATE 4,62:PRINT"  Dist.        Ds"
8250 LOCATE 5,61:PRINT"==================="
8260 LOCATE 6,62:PRINT"     0-300 "
8270 LOCATE 7,62:PRINT"   301-5000"
8280 LOCATE 8,62:PRINT"Beyond 5000"
8290 LOCATE 6,75:PRINT USING "##.##";SF125
8300 LOCATE 7,75:PRINT USING "##.##";SF1
8310 LOCATE 8,75:PRINT USING "##.##";SF75
8320 LOCATE 24,1:INPUT "",ANS$:SCREEN 0:WIDTH 80: COLOR 15,1,1: CLS: ON ERROR GO
TO 0: RETURN
8330 REM*********************************************************************
8340 REM SUBROUTINE END
8350 LPRINT CHR$(12);
8360 LPRINT USING "The 95% confidence level equation is: PV=####.###*(Ds)^##.##";
Q;B1
8370 LPRINT: LPRINT USING "The coefficient of determination (r^2 - 'goodness of
fit') is: #.##";R2
8380 LPRINT:LPRINT:LPRINT "Regression Analysis is complete: refer to above infor
mation, and to printed"
8390 LPRINT "Distance vs. Charge weight tables for all future blast designs."
8400 LPRINT
8410 LPRINT "Modified Scaled Distances should be reviewed and renewed:"
8420 LPRINT "    1. At least once a year."
8430 LPRINT "    2. Whenever geological or geographical site conditions change si
gnificantly."
8440 LPRINT "    3. Whenever blasting methods or blast design changes significant
ly."
8450 RETURN
```

APPENDIX 'A': OSMRE PROGRAM USE

The officially approved OSMRE Computer program is listed in full in IBM BASIC between pages 135 and 149. It will run on the IBM PC, PCjr, AT and XT and most IBM "Compatibles". It may be entered directly from the listing, but to avoid the tedium of this very long entry, and to eliminate possible errors in entry, it is available on disc, in BASIC and FORTRAN, as detailed on page 166.

The program is extremely easy to use, and has been developed specifically to enable non-computer trained personnel to perform the necessary calculations to permit compliance with the requirements of Alternative Scaled Distance applications. It will permit the print-out of entered data as a record of blast vibrations used in the calculations, and will automatically follow the regulations in terms of permissible velocities at different distances. It will permit viewing a plot of the data and the 95% confidence level attenuation curve on the monitor screen, and it provides full data editing and storage/recall from floppy discs. It permits the printing out of a complete Charge Weight/Distance Table for each of the regulatory maximum velocity distance ranges. It also prints out the 95% upper confidence level attenuation formula, together with the coefficient of determination ("goodness of fit") to enable all non-regulatory prediction calculations to be performed.

Following loading the program into the computer, it will be found that the clear prompts, and built-in error protection will enable virtually anyone to follow the proper procedures. The program will not permit extrapolation beyond the limits of the experimental data, although the Charge Weight/Distance Tables will print out "permissible" Charge Weights possibly greatly in excess of the range of collected data. This is because the regulations themselves do not limit charge weights as such, only Scaled Distances, and once a particular scaled distance is permitted, then, strictly speaking, it may be expressed as any combination of distance and charge weight together. For this reason, the user is warned that he must exercise caution and discrimination, and that he should refer to the discussions on this subject on pages 133 and 134, and page 22.

Returning to the exercise on the Blackrock Mine #2 Pit Overburden data, the following pages show a printout from the OSMRE Program, as follows: page 151: "Input data summary", page 152: "OSM Charge Weight Table for 0 - 300 ft.", page 153: "OSM Charge Weight Table for 301 - 5000 ft.", page 154: "OSM Charge Weight Table for 5001 ft. and beyond", and on page 155 the 95% confidence level formula, the "goodness of fit" and a warning on review and renewal.

Input data summary for:

Blackrock Coal Company, Eaglefeather Mine,
Blackrock Wyorado. September 3, 1986.
#2 Pit Overburden: Alternative Scaled Dist.

NOTE: Scaled Distance for reference only. Page, 1

Line No.	Distance/ft.	Charge/lb.	Peak Velocity/ips	Scaled Dist.*
1	220	230	1.10	14.5
2	800	925	0.36	26.3
3	1200	110	0.02	114.4
4	220	560	1.40	9.3
5	920	690	0.34	35.0
6	1200	420	0.28	58.6
7	2050	245	0.02	131.0
8	1200	85	0.02	130.2
9	800	125	0.17	71.6
10	2050	135	0.01	176.4
11	800	1570	0.86	20.2
12	2050	110	0.01	195.5
13	1200	430	0.28	57.9
14	920	247	0.18	58.5
15	800	250	0.24	50.6
16	460	270	0.84	28.0
17	800	1240	0.48	22.7
18	2050	250	0.03	129.7
19	1200	160	0.04	94.9
20	460	480	0.38	21.0
21	225	530	1.10	9.8
22	460	650	0.50	18.0
23	920	330	0.21	50.6
24	800	745	0.33	29.3
25	460	970	0.98	14.8
26	460	1100	0.94	13.9
27	2050	190	0.02	148.7
28	800	950	0.42	26.0
29	920	260	0.13	57.1
30	800	1530	0.51	20.5
31	800	1160	0.82	23.5

Appx. 'A': OSMRE program example

```
OSM Charge Weight per Delay Table for 0 - 300 ft
based on 31 data pairs for:
Blackrock Coal Company,  Eaglefeather Mine,
Blackrock Wyorado.        September 3, 1986.
#2 Pit Overburden: Alternative Scaled Dist.
```

The scaled distance for this distance range is 23.56

Dist(ft)		Charge(lb)	Dist(ft)		Charge(lb)	Dist(ft)		Charge(lb)
50	-	5	134	-	32	218	-	86
52	-	5	136	-	33	220	-	87
54	-	5	138	-	34	222	-	89
56	-	6	140	-	35	224	-	90
58	-	6	142	-	36	226	-	92
60	-	6	144	-	37	228	-	94
62	-	7	146	-	38	230	-	95
64	-	7	148	-	39	232	-	97
66	-	8	150	-	41	234	-	99
68	-	8	152	-	42	236	-	100
70	-	9	154	-	43	238	-	102
72	-	9	156	-	44	240	-	104
74	-	10	158	-	45	242	-	106
76	-	10	160	-	46	244	-	107
78	-	11	162	-	47	246	-	109
80	-	12	164	-	48	248	-	111
82	-	12	166	-	50	250	-	113
84	-	13	168	-	51	252	-	114
86	-	13	170	-	52	254	-	116
88	-	14	172	-	53	256	-	118
90	-	15	174	-	55	258	-	120
92	-	15	176	-	56	260	-	122
94	-	16	178	-	57	262	-	124
96	-	17	180	-	58	264	-	126
98	-	17	182	-	60	266	-	127
100	-	18	184	-	61	268	-	129
102	-	19	186	-	62	270	-	131
104	-	19	188	-	64	272	-	133
106	-	20	190	-	65	274	-	135
108	-	21	192	-	66	276	-	137
110	-	22	194	-	68	278	-	139
112	-	23	196	-	69	280	-	141
114	-	23	198	-	71	282	-	143
116	-	24	200	-	72	284	-	145
118	-	25	202	-	74	286	-	147
120	-	26	204	-	75	288	-	149
122	-	27	206	-	76	290	-	152
124	-	28	208	-	78	292	-	154
126	-	29	210	-	79	294	-	156
128	-	30	212	-	81	296	-	158
130	-	30	214	-	83	298	-	160
132	-	31	216	-	84	300	-	162

Appx. 'A': OSMRE program example

OSM Charge Weight per Delay Table for 301 - 5000 ft
based on 31 data pairs for:
Blackrock Coal Company, Eaglefeather Mine,
Blackrock Wyorado. September 3, 1986.
#2 Pit Overburden: Alternative Scaled Dist.

The scaled distance for this distance range is 26.99

Dist(ft)	Charge(lb)	Dist(ft)	Charge(lb)	Dist(ft)	Charge(lb)
350 -	168	1900 -	4956	3450 -	16339
400 -	220	1950 -	5220	3500 -	16816
450 -	278	2000 -	5491	3550 -	17300
500 -	343	2050 -	5769	3600 -	17791
550 -	415	2100 -	6054	3650 -	18288
600 -	494	2150 -	6345	3700 -	18793
650 -	580	2200 -	6644	3750 -	19304
700 -	673	2250 -	6949	3800 -	19822
750 -	772	2300 -	7262	3850 -	20347
800 -	879	2350 -	7581	3900 -	20879
850 -	992	2400 -	7907	3950 -	21418
900 -	1112	2450 -	8240	4000 -	21964
950 -	1239	2500 -	8580	4050 -	22516
1000 -	1373	2550 -	8926	4100 -	23076
1050 -	1513	2600 -	9280	4150 -	23642
1100 -	1661	2650 -	9640	4200 -	24215
1150 -	1815	2700 -	10007	4250 -	24795
1200 -	1977	2750 -	10381	4300 -	25382
1250 -	2145	2800 -	10762	4350 -	25976
1300 -	2320	2850 -	11150	4400 -	26576
1350 -	2502	2900 -	11545	4450 -	27184
1400 -	2691	2950 -	11946	4500 -	27798
1450 -	2886	3000 -	12355	4550 -	28419
1500 -	3089	3050 -	12770	4600 -	29047
1550 -	3298	3100 -	13192	4650 -	29682
1600 -	3514	3150 -	13621	4700 -	30324
1650 -	3737	3200 -	14057	4750 -	30972
1700 -	3967	3250 -	14499	4800 -	31628
1750 -	4204	3300 -	14949	4850 -	32290
1800 -	4448	3350 -	15406	4900 -	32959
1850 -	4698	3400 -	15869	4950 -	33635
				5000 -	34318

Although the above charge weights-per-delay are authorized under the regulations, they may exceed, or greatly exceed, practical limitations.

Appx. 'A': OSMRE program example

OSM Charge Weight per Delay Table for 5001 ft and beyond
based on 31 data pairs for:
Blackrock Coal Company, Eaglefeather Mine,
Blackrock Wyorado. September 3, 1986.
#2 Pit Overburden: Alternative Scaled Dist.

The scaled distance for this distance range is 32.16

Dist(ft)		Charge(lb)	Dist(ft)		Charge(lb)	Dist(ft)		Charge(lb)
5050	-	24657	7550	-	55113	10050	-	97654
5100	-	25148	7600	-	55845	10100	-	98628
5150	-	25643	7650	-	56582	10150	-	99607
5200	-	26144	7700	-	57324	10200	-	100591
5250	-	26649	7750	-	58071	10250	-	101579
5300	-	27159	7800	-	58823	10300	-	102573
5350	-	27674	7850	-	59580	10350	-	103571
5400	-	28193	7900	-	60341	10400	-	104574
5450	-	28718	7950	-	61107	10450	-	105582
5500	-	29247	8000	-	61878	10500	-	106595
5550	-	29781	8050	-	62654	10550	-	107612
5600	-	30320	8100	-	63435	10600	-	108635
5650	-	30864	8150	-	64220	10650	-	109662
5700	-	31413	8200	-	65011	10700	-	110694
5750	-	31966	8250	-	65806	10750	-	111731
5800	-	32525	8300	-	66606	10800	-	112773
5850	-	33088	8350	-	67411	10850	-	113820
5900	-	33656	8400	-	68221	10900	-	114871
5950	-	34229	8450	-	69035	10950	-	115927
6000	-	34806	8500	-	69855	11000	-	116988
6050	-	35389	8550	-	70679	11050	-	118054
6100	-	35976	8600	-	71508	11100	-	119125
6150	-	36569	8650	-	72342	11150	-	120201
6200	-	37166	8700	-	73181	11200	-	121281
6250	-	37767	8750	-	74024	11250	-	122367
6300	-	38374	8800	-	74873	11300	-	123457
6350	-	38986	8850	-	75726	11350	-	124552
6400	-	39602	8900	-	76584	11400	-	125651
6450	-	40223	8950	-	77447	11450	-	126756
6500	-	40849	9000	-	78315	11500	-	127865
6550	-	41480	9050	-	79187	11550	-	128980
6600	-	42116	9100	-	80065	11600	-	130099
6650	-	42756	9150	-	80947	11650	-	131223
6700	-	43402	9200	-	81834	11700	-	132352
6750	-	44052	9250	-	82726	11750	-	133485
6800	-	44707	9300	-	83623	11800	-	134624
6850	-	45367	9350	-	84524	11850	-	135767
6900	-	46032	9400	-	85431	11900	-	136915
6950	-	46701	9450	-	86342	11950	-	138068
7000	-	47375	9500	-	87258	12000	-	139226
7050	-	48055	9550	-	88179	12050	-	140389
7100	-	48739	9600	-	89105	12100	-	141556
7150	-	49428	9650	-	90035	12150	-	142728
7200	-	50121	9700	-	90971	12200	-	143905
7250	-	50820	9750	-	91911	12250	-	145087
7300	-	51523	9800	-	92856	12300	-	146274
7350	-	52231	9850	-	93806	12350	-	147466
7400	-	52945	9900	-	94761	12400	-	148662
7450	-	53662	9950	-	95720	12450	-	149864
7500	-	54385	10000	-	96685	12500	-	151070

Although the above charge weights-per-delay are authorized under the regulations, they may exceed, or greatly exceed, practical limitations.

Appx. 'A': OSMRE program example

The 95% confidence level equation is: PV= 223.50*(Ds)^-1.64

The coefficient of determination (r^2 - 'goodness of fit') is: 0.91

Regression Analysis is complete: refer to above information, and to printed Distance vs. Charge weight tables for all future blast designs.

Modified Scaled Distances should be reviewed and renewed:

1. At least once a year.
2. Whenever geological or geographical site conditions change significantly.
3. Whenever blasting methods or blast design changes significantly.

APPENDIX 'A': VIBRA-TECH REGRESSION PROGRAM NOTES.

Also available is a rather less sophisticated computer program, written in BASIC. This program can be regarded as complementary to the Approved OSMRE Program, since it is aimed principally at general vibration control and prediction rather than specific OSMRE Regulations compliance. It will permit somewhat greater versatility in performing prediction calculations, and demands greater operator familiarity with prediction techniques. It is not essential for compliance with OSMRE regulations. For identical data input, however, it will arrive at precisely the same 95% confidence level attenuation formula and "goodness of fit", so that mathematically it is equally valid, and can be used for compliance if desired.

The first departure from the OSMRE program occurs when the user is asked to specify square or cube root scaled distance scaling. This to enable regression analyses to be performed on air overpressure. While it is acknowledged that air overpressure predictions have to be made with the utmost caution because of the large number of variables involved, and therefore they should be undertaken only with great care and circumspection, nevertheless it is felt that the ability to examine possibilities in this area should not be denied the operator. If the cube root scaling option is chosen, then vibration unit references continue in terms of PSI rather than in INS/SEC.

Data entry is somewhat different, and no provision is made for data storage to, or recall from, diskettes. Prompts are given for specific name, address, date and operation details entry, and as the program proceeds a printout is made giving a complete record of the analysis. A warning is given at the beginning that at least 30 data pairs should be used, but analysis can be run on considerably less. If analysis is made on less, the printout contains the warning that more data is needed for a valid analysis. At the conclusion of data entry, an opportunity is given for correcting any erroneous entries. Data is printed as entered, and then reprinted as corrected.

The output then follows: the 95% confidence level and the 50% confidence level formulas are given, together with the coefficient of determination and the standard deviation. According to the "goodness" of the coefficient of determination, and depending on the number of data pairs input, appropriate warnings or comments are made. Following this, coordinates for drawing the curves, the 50%, and both upper and lower bound 95% confidence level curves, are given at the maximum and at the minimum scaled distances of the input data. The reason for this is simply that, particularly when communicating with citizen groups where the tendency is to stress "worst-case scenarios", the velocities given are always maximums. Citizen groups, etc., who discuss these velocities forget this in many cases, and it is frequently very useful to be able to point out that while the worst-case velocities may in fact occur occasionally, perhaps 5% of the time, MOST of the time the velocities will best be indicated by the 50% regression line, while occasionally, perhaps 5% of the time, the velocities may even be as LOW as is indicated by the lower bound curve.

The more significant departure from the OSMRE program now occurs. The user is asked to enter the MAXIMUM DESIRED vibration level. This now has no automatic reference to OSMRE regulations. It may have, if the user is applying for a modified scaled distance formula, or if the user wishes to control his blast vibrations in accordance with the Figure 1 (OSMRE Regulations) Blasting Level Chart. On the other hand, the operator may simply wish to conduct blasting operations as close as possible to one of his own mine installations. If, on the advice of his consultant, it was considered that 4 or even 6 inches per second was a safe maximum velocity, then this is the figure that would be input. Whatever level is chosen, for whatever reason, regulatory or protective, the program then prints out a scaled distance that should result in a velocity not exceeding this. Based on this scaled distance, the program then permits calculations of maximum charge weight against a minimum distance, and minimum distances against a specific charge weight.

The following pages show a printout of a regression analysis performed with the Vibra-Tech program, using the identical data input as the OSMRE program. In this case, however, it is presumed that the user wishes to comply with the Regulations in accordance with the Blasting Level Chart, and that the vibration analyses show that the predominant frequencies lie above 30 Hz. He will therefore choose 2" per second as his maximum permissible velocity, and the derived "safe" scaled distance, and the following calculations, are all based on this maximum velocity.

The regression curve example on page 161, and the "Blaster Aid" curve example on page 162, are self-explanatory. They may be drawn from the output of either of the regression analysis programs (OSMRE providing the upper bound line only) though they are not essential to any prediction or compliance technique, only supportive. The "Blaster Aid" curve simply translates a scaled distance into a Distance vs. Charge Weight per Delay curve, for the convenience of field personnel.

APPENDIX 'A': V-T COMPUTER PROGRAM EXAMPLE

VIBRA-TECH ENGINEERS INC. 8120 N. SHERIDAN BLVD. SUITE 304A
WESTMINSTER, COLORADO 80003. TELEPHONE: (303) 429-1996

```
*********************************************************
*          LEAST-SQUARES REGRESSION ANALYSIS            *
*********************************************************
```

Date: 09/03/1985
Company: BLACKROCK COAL COMPANY
Address: EAGLEFEATHER MINE BLACKROCK WYORADO
Operation: #2 PIT OVERBURDEN

* GROUND MOTION ANALYSIS *

31 Data pairs

NO.	DIST	E/MAX	PV
1	220	230	1.1
2	800	925	.36
3	1200	110	.02
4	220	560	1.4
5	920	690	.34
6	1200	420	.28
7	2050	245	.02
8	1200	85	.02
9	800	125	.17
10	2050	135	.01
11	800	1570	.86
12	2050	110	.01
13	1200	430	.28
14	920	247	.18
15	800	250	.24
16	460	270	.84
17	800	1240	.48
18	2050	250	.03
19	1200	160	.04
20	460	480	.38
21	225	530	1.1
22	460	650	.5
23	920	330	.21
24	800	745	.33
25	460	970	.98
26	460	1100	.94
27	2050	190	.02
28	800	950	.42
29	920	260	.13
30	800	1530	.51
31	800	1160	.82

SQUARE ROOT SCALING

E/MAX LBS	DIST FT	1/2 Ds	PV IPS
230	220	14.5	1.1

V-T computer program example

925	800	26.3	.36
110	1200	114.4	.02
560	220	9.3	1.4
690	920	35	.34
420	1200	58.6	.28
245	2050	131	.02
85	1200	130.2	.02
125	800	71.6	.17
135	2050	176.4	.01
1570	800	20.2	.86
110	2050	195.5	.01
430	1200	57.9	.28
247	920	58.5	.18
250	800	50.6	.24
270	460	28	.84
1240	800	22.7	.48
250	2050	129.7	.03
160	1200	94.9	.04
480	460	21	.38
530	225	9.8	1.1
650	460	18	.5
330	920	50.6	.21
745	800	29.3	.33
970	460	14.8	.98
1100	460	13.9	.94
190	2050	148.7	.02
950	800	26	.42
260	920	57.1	.13
1530	800	20.5	.51
1160	800	23.5	.82

The attenuation formulas are:

PV= 223.502 *(Ds)^-1.641 (95% Confidence level)

PV= 89.473 *(Ds)^-1.641 (50% Confidence level)

Coefficient of determination ('Goodness of fit')= .908 (1.0 = Perfect)

This shows EXCELLENT fit of data: it may be used with confidence

Standard Deviation = .458 (0=PERFECT)

COORDINATES FOR DRAWING CURVE:

At Ds = 9.3 Max. PV = 5.75 Inches per Second (95%+)
At Ds = 9.3 Avg. PV = 2.3 Inches per Second (50%)
At Ds = 9.3 Min. PV = .92 Inches per Second (95%-

At Ds = 100 Max. PV = .117 Inches per Second (95%+)
At Ds = 100 Avg. PV = .047 Inches per Second (50%)
At Ds = 100 Min. PV = .019 Inches per Second (95%-)

At Ds = 195.46 Max. PV = .039 Inches per Second (95%+)
At Ds = 195.46 Avg. PV = .016 Inches per Second (50%)
At Ds = 195.46 Min. PV = .006 Inches per Second (95%-)

V-T computer program example

MAXIMUM desired ground vibration is: 2 inches per second

In order NOT TO EXCEED 2 IPS, use a scaled distance NO LESS than:

< 17.69 >

At a distance of 188 feet, NO MORE THAN:
112 lbs per delay must be fired
in order that 2 ins/second NOT BE EXCEEDED!

At a distance of 351 feet, NO MORE THAN:
393 lbs per delay must be fired
in order that 2 ins/second NOT BE EXCEEDED!

If minimum charge per delay that MUST be fired is:
112 lbs, then it must be AT LEAST
188 feet distant from any critical structure where
2 ins/sec MUST NOT BE EXCEEDED!

If minimum charge per delay that MUST be fired is:
85 lbs, then it must be AT LEAST
164 feet distant from any critical structure where
2 ins/sec MUST NOT BE EXCEEDED!

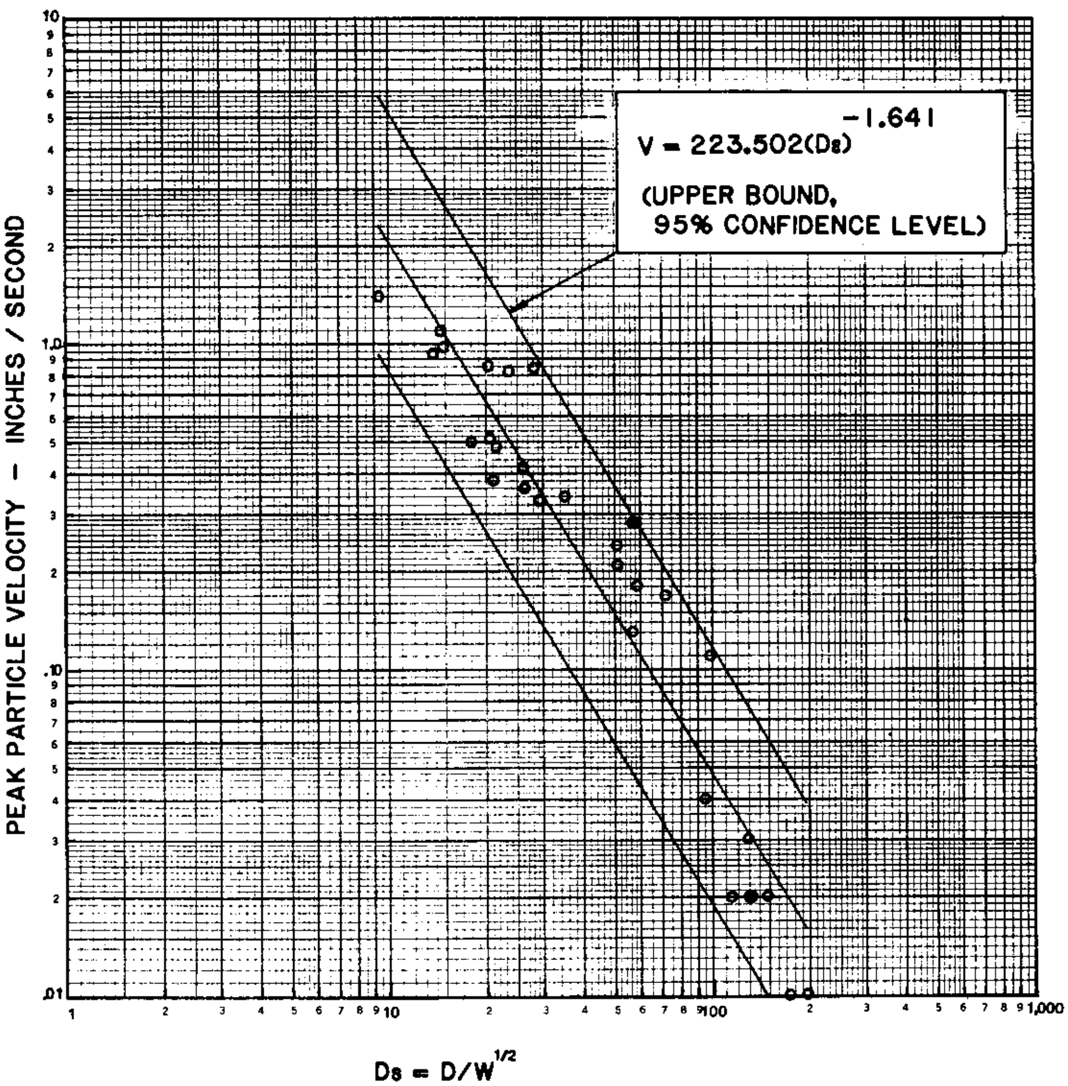
BLACKROCK COAL COMPANY
09/03/1985

VIBRA-TECH ENGINEERS INC.
WESTMINSTER, COLORADO

REGRESSION CURVE EXAMPLE

BLACKROCK COAL COMPANY
EAGLEFEATHER MINE
BLACKROCK, WYORADO

VELOCITY ATTENUATION CURVE : 31 data pairs :

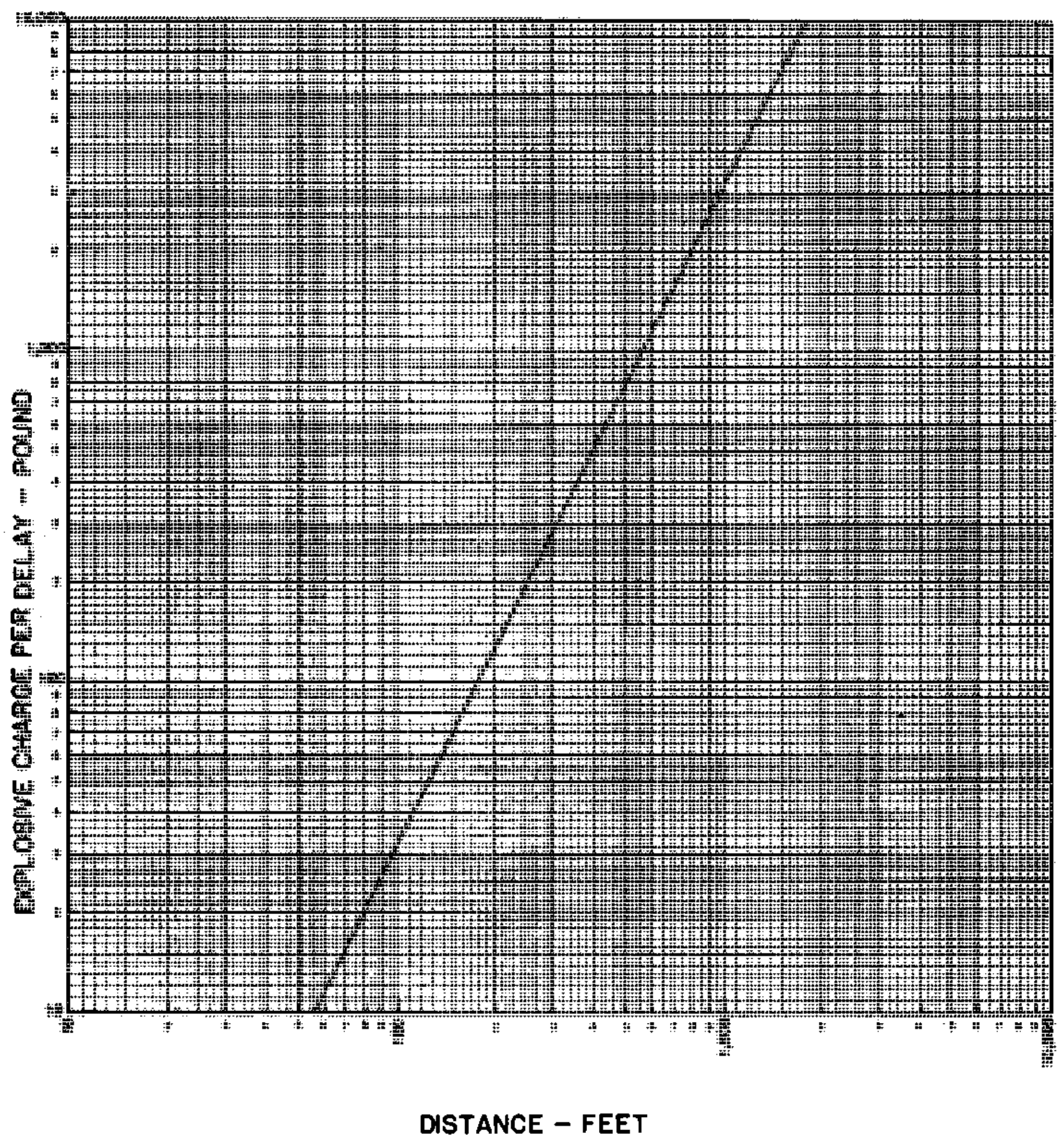


'Blaster Aid' curve example

EXPLOSIVE CHARGE WEIGHT PER DELAY vs. DISTANCE

$V=223.502(Ds)^{-1.641}$ (95% CONFIDENCE LEVEL)

MAX. VELOCITY : 2.0"/SECOND : Ds = 17.69



APPENDIX 'A': V-T CALCULATOR PROGRAM

The following calculator program may be used with the Texas Instruments Ti 59 calculator and stored on a magnetic card for ease of further loading. It will require both sides of a standard TI magnetic card. It will provide the 50% probability formula, the standard deviation, the coefficient of determination, and it will calculate PV against Scaled Distance, to a 50% confidence level. It will provide the "Safe" Scaled Distance, to a 95% confidence level, on the input of a maximum desired or allowed particle velocity. Based on this 95% confidence level Scaled Distance, it will calculate maximum charge weight per delay against distance. Following these calculations, the 95% confidence level formula may be determined, since recalling memory register 29 will display the 95% confidence level 'y' axis intercept. Used in conjunction with the formulae provided in Appendix 'B' it will therefore permit full regression analysis, and all necessary calculations required for all OSMRE Regulations compliance and vibration predictions.

Data entry is simply scaled distance versus particle velocity (hence the references throughout the text to "data pairs" - these are the data pairs used in all the calculations), so that the first step is to calculate all scaled distances from the data distances and charge weights. Remember that the computer programs incorporate this calculation, and do not round off the results: if it is wished to compare results from a computer program with the calculator program, scaled distances must be used which are not rounded off. This would not be necessary in normal practice, so this fact might be recalled should the results of any calculations differ slightly. The mathematics are identical, however.

For the first data pair, enter scaled distance, then press "A". Enter the first particle velocity, then press "B". Following each such data pair entry, the display will show the number of data pairs entered. Repeat this procedure for each data pair until all have been entered. Press "C" to calculate the slope, "D" to calculate the 'y' axis intercept, and "E" to calculate the standard deviation. Pressing "E'" will show the coefficient of determination, r^2. Coordinates for the 50% curve may be obtained by entering any scaled distance and pressing "A'", when the display will then show the corresponding particle velocity. Entering any particle velocity that it is desired NOT to exceed, and then pressing "B'", will then display the minimum scaled distance to use. Entering a distance in feet, and then pressing "C'" will calculate the maximum allowable charge per delay based on this scaled distance. As already mentioned, recalling memory register 29 will permit the 95% confidence formula to be determined.

Always use caution, for no guidance or warnings are provided!

V-T calculator program

000	76	LBL
001	11	A
002	23	LNX
003	32	X:T
004	25	CLR
005	91	R/S
006	76	LBL
007	12	B
008	23	LNX
009	78	Σ+
010	91	R/S
011	76	LBL
012	13	C
013	43	RCL
014	01	01
015	65	×
016	43	RCL
017	04	04
018	55	÷
019	43	RCL
020	03	03
021	95	=
022	42	STO
023	10	10
024	43	RCL
025	06	06
026	75	-
027	43	RCL
028	10	10
029	95	=
030	42	STO
031	11	11
032	43	RCL
033	04	04
034	33	X^2
035	55	÷
036	43	RCL
037	03	03
038	95	=
039	42	STO
040	12	12
041	43	RCL
042	05	05
043	75	-
044	43	RCL
045	12	12
046	95	=
047	42	STO
048	13	13
049	43	RCL
050	11	11
051	55	÷
052	43	RCL
053	13	13
054	95	=
055	42	STO
056	14	14
057	91	R/S
058	76	LBL
059	14	D
060	43	RCL
061	04	04
062	55	÷
063	43	RCL
064	03	03
065	65	×
066	43	RCL
067	14	14
068	95	=
069	42	STO
070	15	15
071	43	RCL
072	01	01
073	55	÷
074	43	RCL
075	03	03
076	95	=
077	75	-
078	43	RCL
079	15	15
080	95	=
081	22	INV
082	23	LNX
083	42	STO
084	16	16
085	91	R/S
086	76	LBL
087	15	E
088	43	RCL
089	01	01
090	55	÷
091	43	RCL
092	14	14
093	95	=
094	42	STO
095	17	17
096	43	RCL
097	04	04
098	75	-
099	43	RCL
100	17	17
101	95	=
102	42	STO
103	18	18
104	43	RCL
105	16	16
106	23	LNX
107	65	×
108	43	RCL
109	18	18
110	95	=
111	75	-
112	43	RCL
113	06	06
114	95	=
115	42	STO
116	19	19
117	43	RCL
118	14	14
119	65	×
120	02	2
121	65	×
122	43	RCL
123	19	19
124	95	=
125	42	STO
126	20	20
127	43	RCL
128	16	16
129	23	LNX
130	33	X^2
131	42	STO
132	21	21
133	43	RCL
134	03	03
135	35	1/X
136	42	STO
137	22	22
138	43	RCL
139	14	14
140	33	X^2
141	65	×
142	43	RCL
143	05	05
144	85	+
145	43	RCL
146	02	02
147	85	+
148	43	RCL
149	20	20

V-T calculator program

150	95	=
151	65	×
152	43	RCL
153	22	22
154	95	=
155	85	+
156	43	RCL
157	21	21
158	95	=
159	34	√X
160	42	STO
161	23	23
162	91	R/S
163	76	LBL
164	10	E'
165	43	RCL
166	11	11
167	33	X^2
168	42	STO
169	24	24
170	43	RCL
171	01	01
172	33	X^2
173	55	÷
174	43	RCL
175	03	03
176	95	=
177	42	STO
178	25	25
179	43	RCL
180	02	02
181	75	-
182	43	RCL
183	25	25
184	95	=
185	65	×
186	43	RCL
187	13	13
188	95	=
189	42	STO
190	26	26
191	43	RCL
192	24	24
193	55	÷
194	43	RCL
195	26	26
196	95	=
197	91	R/S
198	76	LBL
199	16	A'
200	42	STO
201	27	27
202	43	RCL
203	16	16
204	65	×
205	53	(
206	43	RCL
207	27	27
208	45	Y^X
209	43	RCL
210	14	14
211	54	)
212	95	=
213	91	R/S
214	76	LBL
215	17	B'
216	42	STO
217	28	28
218	53	(
219	53	(
220	43	RCL
221	23	23
222	65	×
223	02	2
224	54	)
225	22	INV
226	23	LNX
227	65	×
228	43	RCL
229	16	16
230	54	)
231	42	STO
232	29	29
233	53	(
234	43	RCL
235	28	28
236	55	÷
237	43	RCL
238	29	29
239	54	)
240	45	Y^X
241	43	RCL
242	14	14
243	35	1/X
244	95	=
245	42	STO
246	30	30
247	91	R/S
248	76	LBL
249	18	C'
250	42	STO
251	31	31
252	53	(
253	43	RCL
254	31	31
255	55	÷
256	43	RCL
257	30	30
258	54	)
259	33	X^2
260	95	=
261	91	R/S

COMPUTER AND CALCULATOR PROGRAM AVAILABILITY

The three computer/calculator programs described in Appendix 'A' of this manual are:

1. The OSMRE Approved Regression Analysis Computer Program. This program, written by OSMRE engineers, is designed specifically to permit compliance with the Modified Scaled Distance Option, [(Section 816.67(d)(3)(ii)]. It will also permit compliance with other options, since it provides the 95% upper confidence level vibration attenuation formula from which all other prediction calculations may be made. It will permit data storage onto disc, and data retrieval from disc. It will run on IBM PC and compatibles. The program is written in BASIC and FORTRAN on a 5¼" Floppy Diskette, and includes full instructions for use.

2. The V-T "General Use" Regression Analysis Computer Program. This program is not specific to any particular OSMRE Regulations compliance option, but permits more versatile prediction and control. It will also permit full OSMRE compliance. It does not provide for data storage or retrieval on disc. It will run on IBM PC and compatibles. The program is written in BASIC only on a 5¼" Floppy Diskette, and includes full instructions for use.

3. The V-T Regression Analysis Program for the Ti59 Calculator. This is a simplified calculator program that will permit both OSMRE Regulations compliance and prediction and control, since it will provide the 95% confidence level attenuation formula. The program is stored on a Ti Magnetic Card, and includes full instructions for use.

Any of the above may be obtained by calling the following toll-free number:

1-800-233-6181

APPENDIX 'B'

USEFUL FORMULAE

USEFUL FORMULAE

1. SCALED DISTANCE RELATIONSHIPS:

$$Ds = D/W^{\frac{1}{2}} \qquad W = (D/Ds)^2 \qquad D = Ds \times W^{\frac{1}{2}}$$

Where D = distance, feet; and W = charge weight per delay, lbs.

2. VELOCITY ATTENUATION CURVE RELATIONSHIPS:

$$PV = H \times (Ds)^{-\beta} \qquad Ds = (H/V)^{1/\beta}$$

Where H = y axis intercept @ Ds = 1 and β = slope.

3. AIR OVERPRESSURE :

$$dB = 20 \log (P/Po)$$

where P = OVERPRESSURE, P.S.I.

and $Po = 2.9 \times 10^{-9}$ (base reference pressure).

4. GENERAL: SEISMIC MOTION:

$PV = 2\pi fA$ where f = frequency, Hz

A = single displacement, ins.

$$A = \frac{PV}{2\pi f}$$

$$f = \frac{PV}{2\pi A} \qquad VR = (L^2 + V^2 + T^2)^{\frac{1}{2}}$$

NOTE: <u>TRUE</u> Resultant: Waveform must be searched to find Max VR, where L, V, & T all occur at the same instant, otherwise VR is <u>PSEUDO</u> Resultant.

$ER = 0.274\ VR^2$ ("Energy Ratio")

5. ACCELERATION:

$$g = \frac{2\pi fV}{386}\ ; \quad g = \frac{4\pi^2 f^2 A}{386}\ ; \quad PV = \frac{386g}{2\pi f}$$

APPENDIX 'C'

GLOSSARY

GLOSSARY

From Bureau of Mines Information Circular IC 8925, 1983.

ACOUSTICAL IMPEDANCE. -The mathematical expression characterizing a material as to its energy transfer properties. The product of its unit density and its sonic velocity.

ADOBE CHARGES. -See mud cap.

AIRBLAST. -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. Airblast may or may not be audible.

AIRDOX. -A system that uses 10,000 psi compressed air to break undercut coal. Airdox will not ignite a gassy or dusty atmosphere.

ALUMINUM. -A metal commonly used as a fuel or sensitizing agent in explosives and blasting agents. Normally used in finely divided particle or flake form.

AMERICAN TABLE OF DISTANCES. -A quantity/distance table published by IME as Pamphlet No. 2, which specifies safe explosive storage distances from inhabited buildings, public highways, passenger railways and other stored explosives materials.

AMMONIUM NITRATE (AN). -The most commonly used oxidizer in explosives and blasting agents. Its formula is NH_4NO_3.

ANFO. -An explosive material consisting of ammonium nitrate and fuel oil. The most commonly used blasting agent.

AXIAL PRIMING. -A system for priming blasting agents in which a core of priming material extends through most or all of the blasting agent charge length.

BACK BREAK. -Rock broken beyond the limits of the last row of holes.

BACK HOLES. -The top holes in a tunnel or drift round.

BASE CHARGE. -The main explosive charge in a detonator.

BATF. -Bureau of Alcohol, Tobacco and Firearms, U.S. Department of the Treasury, which enforces explosives control and security regulations.

Glossary

BEDS OR BEDDING. -Layers of sedimentary rock, usually separated by a surface of discontinuity. As a rule, the rock can be readily separated along these planes.

BENCH. -The horizontal ledge in a quarry face along which holes are drilled vertically. Benching is the process of excavating whereby terraces or ledges are worked in a stepped sequence.

BINARY EXPLOSIVE. -An explosive based on two nonexplosive ingredients, such as nitromethane and ammonium nitrate, which are shipped and stored separately and mixed at the jobsite to form a high explosive.

BLACK POWDER. -A low explosive consisting of sodium or potassium nitrate, carbon, and sulfur. Black powder is seldom used today because of its low energy, poor fume quality, and extreme sensitivity to sparks.

BLAST. -The detonation of explosives to break rock.

BLAST AREA. -The area near a blast within the influence of flying rock missiles, or concussion.

BLASTER. -A qualified person in charge of a blast. Also, a person (blaster-in-charge) who has passed a test, approved by OSM, which certifies his or her qualifications to supervise blasting activities.

BLASTERS' GALVANOMETER; BLASTERS' MULTIMETER. -See galvanometer; multimeter.

BLASTHOLE. -A hole drilled in rock or other material for the placement of explosives.

BLASTING AGENT. -An explosive that meets prescribed criteria for insensitivity to initiation. For storage, any material or mixture consisting of a fuel and oxidizer, intended for blasting, not otherwise defined as an explosive, provided that the finished product, as mixed and packaged for use or shipment, cannot be detonated by means of a No. 8 test blasting cap when unconfined (BATF). For transportation, a material designed for blasting which has been tested in accordance with CFR49, Section 173.14a, and found to be so insensitive that there is very little probability of accidental initiation to explosion or transition from deflagration to detonation (DOT).

BLASTING CAP. -A detonator that is initiated by safety fuse (MSHA). See also detonator.

BLASTING CIRCUIT. -The electrical circuit used to fire one or more electric blasting caps.

BLASTING CREW. -A group of persons whose purpose is to load explosive charges.

BLASTING MACHINE. -Any machine built expressly for the purpose of energizing electric blasting caps or other types of initiator.

BLASTING MAT. -See mat.

BLASTING SWITCH. -A switch used to connect a power source to a blasting circuit.

BLISTERING. -See mud cap.

BLOCKHOLE. -A hole drilled into a boulder to allow the placement of a small charge to break the boulder.

BOOSTER. -A unit of explosive or blasting agent used for perpetuating or intensifying an explosive reaction. A booster does not contain an initiating device but is often cap sensitive.

BOOTLEG. -That portion of a borehole that remains relatively intact after having been charged with explosive and fired. A bootleg may contain unfired explosive and should be considered hazardous.

BOREHOLE (Blasthole). -A drilled hole, usually in rock, into which explosives are loaded for blasting.

BOREHOLE PRESSURE. -The pressure which the hot gases of detonation exert on the borehole wall. Borehole pressure is primarily a function of the density of the explosive and the heat of explosion.

BRIDGE WIRE. -A very fine filament wire imbedded in the ignition element of an electric blasting cap. An electric current passing through the wire causes a sudden heat rise, causing the ignition element to be ignited.

BRISANCE. -A property of an explosive roughly equivalent to detonation velocity. An explosive with a high detonation velocity has high brisance.

BUBBLE ENERGY. -The expanding gas energy of an explosive, as measured in an underwater test.

BULK MIX. -A mass of explosive material prepared for use without packaging.

BULK STRENGTH. -A strength of an explosive per unit volume.

BULLDOZE. -See mud cap.

BURDEN. -The distance from an explosive charge to the nearest free or open face. Technically, there may be an apparent burden and a true burden, the latter being measured in the direction in which displacement of broken rock will occur following firing of the explosive charge. Also, the amount of material to be blasted by a given hole, given in tons or cubic yards.

BURN CUT. -A parallel hole cut employing several closely spaced blastholes. Not all of the holes are loaded with explosive. The cut creates a cylindrical opening by shattering the rock.

BUS WIRES. -The two wires, joined to the connecting wire, to which the leg wires of the electric caps are connected in a parallel circuit. Each leg wire of each cap is connected to a different bus wire. In a series-in-parallel circuit, each end of each series is connected to a different bus wire.

BUTT. -See bootleg.

CAP. -See detonator.

CAPPED FUSE. -A length of safety fuse to which a blasting cap has been attached.

CAPPED PRIMER. -A package or cartridge of cap-sensitive explosive which is specifically designed to transmit detonation to other explosives and which contains a detonator (MSHA).

CAP SENSITIVITY. -The sensitivity of an explosive to initiation, expressed in terms of an IME No. 8 test detonator or a fraction thereof.

CARBON MONOXIDE. - A poisonous gas created by detonating explosive materials. Excessive carbon monoxide is caused by an inadequate amount of oxygen in the explosive mixture (excessive fuel).

CARDOX. -A system that uses a cartridge filled with liquid carbon dioxide, which, when initiated by a mixture of potassium perchlorate and charcoal, creates a pressure adequate to break undercut coal.

CARTRIDGE. -A rigid or semirigid container of explosive or blasting agent of a specified length or diameter.

CARTRIDGE COUNT. -The number of $1\frac{1}{4}$- by 8-in. cartridges of explosives per 50-lb case.

CARTRIDGE STRENGTH. -A rating that compares a given volume of explosive with an equivalent volume of straight nitroglycerin dynamite, expressed as a percentage.

CAST PRIMER. -A cast unit of explosive, usually pentolite or composition B, commonly used to initiate detonation in a blasting agent.

CHAMBERING. -The process of enlarging a portion of blasthole (usually the bottom) by firing a series of small explosive charges. Chambering can also be done by mechanical or thermal methods.

CHAPMAN-JOUQUET (C-J) PLANE. -In a detonating explosive column, the plane that defines the rear boundary of the primary reaction zone.

CIRCUIT TESTER. -See galvanometer; multimeter.

CLASS A EXPLOSIVE. -Defined by the U.S. Department of Transportation (DOT) as an explosive that possesses detonating or otherwise maximum hazard; such as, but not limited to, dynamite, nitroglycerin, lead azide, black powder, blasting caps, and detonating primers.

CLASS B EXPLOSIVE. -Defined by DOT as an explosive that possesses flammable hazard; such as, but not limited to, propellant explosives, photographic flash powders, and some special fireworks.

CLASS C EXPLOSIVE. -Defined by DOT as an explosive that contains Class A or Class B explosives, or both as components but in restricted quantities. For example, blasting caps or electric blasting caps in lots of less than 1,000.

COLLAR. -The mouth or opening of a borehole or shaft. To collar in drilling means the act of starting a borehole.

COLLAR DISTANCE. -The distance from the top of the powder column to the collar of the blasthole, usually filled with stemming.

COLUMN CHARGE. -A long, continuous charge of explosive or blasting agent in a borehole.

COMMERCIAL EXPLOSIVES. -Explosives designed and used for commercial or industrial, rather than military applications.

COMPOSITION B. -A mixture of RDX and TNT which, when cast, has a density of 1.65 g/cu cm and a velocity of 25,000 fps. It is useful as a primer for blasting agents.

CONDENSER-DISCHARGE BLASTING MACHINE. -A blasting machine that uses batteries or magnets to energize one or more condensers (capacitors) whose stored energy is released into a blasting circuit.

CONFINED DETONATION VELOCITY. -The detonation velocity of an explosive or blasting agent under confinement, such as in a borehole.

CONNECTING WIRE. -A wire, smaller in gage than the lead wire, used in a blasting circuit to connect the cap circuit with the lead wire or to extend leg wires from one borehole to another. Usually considered expendable.

CONNECTOR. -See MS connector.

CONTROLLED BLASTING. -Techniques used to control overbreak and produce a competent final excavation wall. See line drilling, presplitting, smooth blasting, and cushion blasting.

CORDEAU DETONANT FUSE. -A term used to define detonating cord.

CORNISH CUT. -See parallel hole cut.

COROMANT CUT. -See parallel hole cut.

COUPLING. -The degree to which an explosive fills the borehole. Bulk loaded explosives are completely coupled. Untamped cartridges are decoupled. Also, capacitive and inductive coupling from powerlines, which may be introduced into an electric blasting circuit.

COYOTE BLASTING. -The practice of driving tunnels horizontally into a rock face at the foot of the shot. Explosives are loaded into these tunnels. Coyote blasting is used where it is impractical to drill vertically.

CRITICAL DIAMETER. -For any explosive, the minimum diameter for propagation of a stable detonation. Critical diameter is affected by confinement, temperature, and pressure on the explosive.

CROSSLINKING AGENT. -The final ingredient added to a water gel or slurry, causing it to change from a liquid to a gel.

CURRENT LIMITING DEVICE. -A device used to prevent arcing in electric blasting caps by limiting the amount or duration of current flow. Also used in a blaster's galvanometer or multimeter to assure a safe current output.

CUSHION BLASTING. -A surface blasting technique used to produce competent slopes. The cushion holes, fired after the main charge, have a reduced spacing and employ decoupled charges.

CUSHION STICK. -A cartridge of explosive loaded into a small-diameter borehole before the primer. The use of a cushion stick is not generally recommended because of possible resulting bootlegs.

CUT. -An arrangement of holes used in underground mining and tunnel blasting to provide a free face to which the remainder of the round can break. Also the opening created by the cut holes.

CUTOFFS. -A portion of a column of explosives that has failed to detonate owing to bridging or a shifting of the rock formation, often due to an improper delay system. Also a cessation of detonation in detonating cord.

DEAD PRESSING. -Desensitization of an explosive, caused by pressurization. Tiny air bubbles, required for sensitivity, are literally squeezed from the mixture.

DECIBEL. -The unit of sound pressure commonly used to measure airblast from explosives. The decibel scale is logarithmic.

DECK. -A small charge or portion of a blasthole loaded with explosives which is separated from other charges by stemming or an air cushion.

DECOUPLING. -The use of cartridged products significantly smaller in diameter than the borehole. Decoupled charges are normally not used except in cushion blasting, smooth blasting, presplitting, and other situations where crushing is undesirable.

DEFLAGRATION. -A subsonic but extremely rapid explosive reaction accompanied by gas formation and borehole pressure, but without shock.

DELAY BLASTING. -The use of delay detonators or connectors that cause separate charges to detonate at different times, rather than simultaneously.

DELAY CONNECTOR. -A nonelectric, short-interval delay device for use in delaying blasts that are initiated by detonating cord.

DELAY DETONATOR. -A detonator, either electric or nonelectric, with a built-in element that creates a delay between the input of energy and the explosion of the detonator.

DELAY ELECTRIC BLASTING CAP. -An electric blasting cap with a built-in delay that delays cap detonation in predetermined time intervals, from milliseconds up to a second or more, between successive delays.

DELAY ELEMENT. -That portion of a blasting cap which causes a delay between the instant of application of energy to the cap and the time of detonation of the base charge of the cap.

DENSITY. -The weight per unit volume of explosive, expressed as cartridge count or grams per cubic centimeter. See loading density.

DEPARTMENT OF TRANSPORTATION (DOT). -A Federal agency that regulates safety in interstate shipping of explosives and other hazardous materials.

DETALINE SYSTEM. -A nonelectric system for initiating blasting caps in which the energy is transmitted through the circuit by means of a low-energy detonating cord.

DETONATING CORD. -A plastic-covered core of high-velocity explosives, usually PETN, used to detonate charges of explosives. The plastic covering, in turn, is covered with various combinations of textiles and waterproofing.

DETONATION. -A supersonic explosive reaction that propagates a shock wave through the explosive accompanied by a chemical reaction that furnishes energy to sustain the shock wave propagation in a stable manner. Detonation creates both a detonation pressure and a borehole pressure.

DETONATION PRESSURE. -The head-on pressure created by the detonation proceeding down the explosive column. Detonation pressure is a function of the explosive's density and the square of its velocity.

DETONATION VELOCITY. -See velocity.

DETONATORS. -Any device containing a detonating charge that is used to initiate an explosive. Includes, but is not limited to, blasting caps, electric blasting caps, and nonelectric instantaneous or delay blasting caps.

DITCH BLASTING. -See propagation blasting.

DOT. -See Department of Transportation.

DOWNLINE. -The line of detonating cord in the borehole which transmits energy from the trunkline down the hole to the primer.

DRILLING PATTERN. -See pattern.

DROP BALL. -Known also as a headache ball. An iron or steel weight held on a wire rope which is dropped from a height onto large boulders for the purpose of breaking them into smaller fragments.

DYNAMITE. -The high explosive invented by Alfred Nobel. Any high explosive in which the sensitizer is nitroglycerin or a similar explosive oil.

ECHELON PATTERN. -A delay pattern that causes the true burden, at the time of detonation, to be at an oblique angle from the original free face.

ELECTRIC BLASTING CAP. -A blasting cap designed to be initiated by an electric current.

ELECTRIC STORM. -An atmospheric disturbance of intense electrical activity presenting a hazard in all blasting activities.

EMULSION. -An explosive material containing substantial amounts of oxidizers dissolved in water droplets surrounded by an immiscible fuel. Similar to a slurry in some respects.

EXPLODING BRIDGE WIRE (EBW). -A wire that explodes upon application of current. It takes the place of the primary explosive in an electric detonator. An exploding bridge wire detonator is an electric detonator that employs an exploding bridge wire rather than a primary explosive. An exploding bridge wire detonator functions instantaneously.

EXPLOSION. -A thermochemical process in which mixtures of gases, solids or liquids react with the almost instantaneous formation of gaseous pressures and sudden heat release.

EXPLOSION PRESSURE. -See borehole pressure.

EXPLOSIVE. -Any chemical mixture that reacts at high velocity to liberate gas and heat, causing very high pressures. BATF classifications include high explosives and low explosives. Also, any substance classified as an explosive by DOT.

EXPLOSIVE MATERIALS. -A term which includes, but is not necessarily limited to, dynamite and other high explosives, slurries, water gels, emulsions, blasting agents, black powder, pellet powder, initiating explosives, detonators, safety fuses, squibs, detonating cord, igniter cord, and igniters.

EXTRA DYNAMITE. -Also called ammonia dynamite, a dynamite that derives the major portion of its energy from ammonium nitrate.

EXTRANEOUS ELECTRICITY. -Electrical energy, other than actual firing current, which may be a hazard with electric blasting caps. Includes stray current, static electricity, lightning, radio-frequency energy, and capacitive or inductive coupling.

FACE. -A rock surface exposed to air. Also called a free face, a face provides the rock with room to expand from fragmentation.

FIRING CURRENT. -Electric current purposely introduced into a blasting circuit for the purpose of initiation. Also, the amount of current required to activate an electric blasting cap.

FIRING LINE. -A line, often permanent, extending from the firing location to the electric blasting cap circuit. Also called lead wire.

FLASH OVER. -Sympathetic detonation between explosive charges or between charged blastholes.

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.

FRACTURING. -The breaking of rock with or without movement of the broken pieces.

FRAGMENTATION. -The extent to which a rock is broken into pieces by blasting. Also the act of breaking rock.

FUEL. -An ingredient in an explosive which reacts with an oxidizer to form gaseous products of detonation.

FUEL OIL. -The fuel, usually No. 2 diesel fuel, in AN-FO.

FUME CLASSIFICATION. -An IME quantification of the amount of fumes generated by an explosive of blasting agent.

FUME QUALITY. -A measure of the toxic fumes to be expected when a specific explosive is properly detonated. See fumes.

FUMES. -Noxious or poisonous gases liberated from a blast. May be due to a low fume quality explosive or inefficient detonation.

FUSE. -See safety fuse.

FUSE LIGHTER. -A pyrotechnic device for rapid and dependable lighting of safety fuse.

GALVANOMETER. -(More properly called blasters' galvanometer.) A measuring instrument containing a silver chloride cell and/or a current limiting device which is used to measure resistance in an electric blasting circuit. Only a device specifically identified as a blasting galvanometer or blasting multimeter should be used for this purpose.

GAP SENSITIVITY. -A measure of the distance across which an explosive can propagate a detonation. The gap may be air or a defined solid material. Gap sensitivity is a measure of the likelihood of sympathetic propagation.

GAS DETONATION SYSTEM. -A system for initiating caps in which the energy is transmitted through the circuit by means of gas detonation inside a hollow plastic tube.

GELATIN. -An explosive or blasting agent that has a gelatinous consistency. The term is usually applied to a gelatin dynamite but may also be a water gel.

GELATIN DYNAMITE. -A highly water-resistant dynamite with a gelatinous consistency.

GENERATOR BLASTING MACHINE. -A blasting machine operated by vigorously pushing down a rack bar or twisting a handle. Now largely replaced by condenser discharge blasting machines.

GRAINS. -A system of weight measurement in which 7,000 grains equal 1 lb.

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

HANGFIRE. -The detonation of an explosive charge at a time after its designed firing time. A source of serious accidents.

HEADING. -A horizontal excavation driven in an underground mine.

HERCUDET. -See gas detonation system.

HERTZ. -A term used to express the frequency of ground vibrations and airblast. One hertz is one cycle per second.

HIGH EXPLOSIVE. -Any product used in blasting which is sensitive to a No. 8 test blasting cap and reacts at a speed faster than that of sound in the explosive medium. A classification used by BATF for explosive storage.

HIGHWALL. -The bench, bluff or ledge on the edge of a surface excavation. This term is most commonly used in coal strip mining.

IGNITACORD. -A cordlike fuse that burns progressively along its length with an external flame at the zone of burning and is used for lighting a series of safety fuses in sequence. Burns with a spitting flame similar to a Fourth-of-July sparkler.

IME. -The Institute of Makers of Explosives. A trade organization dealing with the use of explosives, concerned with safety in manufacture, transportation, storage, handling and use. The IME publishes a series of blasting safety pamphlets.

INITIATION. -The act of detonating a high explosive by means of a cap, a mechanical device, or other means. Also the act of detonating the initiator.

INSTANTANEOUS DETONATOR. -A detonator that contains no delay element.

JET LOADER. -A system for loading AN-FO into small blastholes in which the AN-FO is drawn from a container by the venturi principle and blown into the hole at high velocity through a semiconductive loading hose.

JOINTS. -Planes within a rock mass along which there is no resistance to separation and along which there has been no relative movement of the material on either side. Joints occur in sets, the planes of which may be mutually perpendicular. Joints are often called partings.

JUMBO. -A machine designed to contain two or more mounted drilling units that may or may not be operated independently.

KERF. -A slot cut in a coal or soft rock face by a mechanical cutter to provide a free face for blasting.

LEAD WIRE. -The wire connecting the electrical power source with the leg wires or connecting wires of a blasting circuit. Also called firing line.

LEDC. -Low energy detonating cord, which may be used to initiate nonelectric blasting caps.

LEG WIRES. -Wire connected to the bridge of an electric blasting cap and extending from the waterproof plug. The opposite ends are used to connect the cap into a circuit.

LIFTERS. -The bottom holes in a tunnel or drift round.

LINE DRILLING. -A method of overbreak control in which a series of very closely spaced holes are drilled at the perimeter of the excavation. These holes are not loaded with explosive.

LIQUID OXYGEN EXPLOSIVE. -A high explosive made by soaking cartridges of carbonaceous materials in liquid oxygen. This explosive is rarely used today.

LOADING DENSITY. -An expression of explosive density in terms of pounds of explosive per foot of charge of a specific diameter.

LOADING FACTOR. -See powder factor.

LOADING POLE. -A pole made of nonsparking material, used to push explosive cartridges into a borehole and to break and tightly pack the explosive cartridges into the hole.

LOW EXPLOSIVE. -An explosive in which the speed of reaction is slower than the speed of sound, such as black powder. A classification used by BATF for explosive storage.

LOX. -See liquid oxygen explosive.

MAGAZINE. -A building, structure, or container specially constructed for storing explosives, blasting agents, detonators, or other explosive materials.

MAT. -A covering placed over a shot to hold down flying material; usually made of woven wire cable, rope, or scrap tires.

MAXIMUM FIRING CURRENT. -The highest current (amperage) recommended for the safe and effective performance of an electric blasting cap.

METALLIZED. -Sensitized or energized with finely divided metal flakes, powders, or granules, usually aluminum.

MICHIGAN CUT. -See parallel hole cut.

MICROBALLOONS. -Tiny hollow spheres of glass or plastic which are added to explosive materials to enhance sensitivity by assuring an adequate content of entrapped air.

MILLISECOND. -The unit of measurement of short delay intervals, equal to 1/1000 of a second.

MILLISECOND DELAY CAPS. -Delay detonators that have built-in time delays of various lengths. The interval between the delays at the lower end of the series is usually 25 ms. The interval between delays at the upper end of the series may be 100 to 300 ms.

MINIMUM FIRING CURRENT. -The lowest current (amperage) that will initiate an electric blasting cap within a specified short interval of time.

MISFIRE. -A charge, or part of a charge, which for any reason has failed to fire as planned. All misfires are dangerous.

MONOMETHYLAMINENITRATE. -A compound used to sensitize some water gels.

MS CONNECTOR. -A device used as a delay in a detonating cord circuit connecting one hole in the circuit with another or one row of holes to other rows of holes.

MHSA. -The Mine Safety and Health Administration. An agency under the Department of Labor which enforces health and safety regulations in the mining industry.

MUCKPILE. -A pile of broken rock or dirt that is to be loaded for removal.

MUD CAP. -Referred to also as adobe, bulldoze, blistering, or plaster shot. A charge of explosive fired in contact with the surface of a rock, usually covered with a quantity of mud, wet earth, or similar substance. No borehole is used.

MULTIMETER. -(More properly called blasters' multimeter.) A multipurpose test instrument used to check line voltages, firing circuits, current leakage, stray currents, and other measurements pertinent to electric blasting. Only a meter specifically designated as a blasters' multimeter or blasters' galvanometer should be used to test electric blasting circuits.

NATIONAL FIRE PROTECTION ASSOCIATION (NFPA). -An industry -government association that publishes standards for explosive material and ammonium nitrate.

NITROCARBONITRATE. -A classification once given to a blasting agent by DOT for shipping purposes. This term is now obsolete.

NITROGEN OXIDES. -Poisonous gases created by detonating explosive materials. Excessive nitrogen oxides may be caused by an excessive amount of oxygen in the explosive mixture (excessive oxidizer), or by inefficient detonation.

NITROGLYCERIN (NG). -The explosive oil originally used as the sensitizer in dynamites, represented by the formula $C_3H_5(ONO_2)_3$.

NITROMETHANE. -A liquid compound used as a fuel in two-component (binary) explosives and as rocket fuel.

NITROPROPANE. -A liquid fuel that can be combined with pulverized ammonium nitrate prills to make a dense blasting mixture.

NITROSTARCH. -A solid explosive, similar to nitroglycerin in function, used as the base of "nonheadache" powders.

NONEL. -See shock tube system.

NONELECTRIC DELAY BLASTING CAP. -A detonator with a delay element, capable of being initiated nonelectrically. See shock tube system; gas detonation system; Detaline System.

NO. 8 TEST BLASTING CAP. -See test blasting cap No. 8.

OSHA. -The Occupational Safety and Health Administration. An agency under the Department of Labor which enforces health and safety regulations in the construction industry, including blasting.

OSMRE. -The Office of Surface Mining Reclamation and Enforcement. An agency under the Department of Interior which enforces surface environmental regulations in the coal mining industry.

OVERBREAK. -Excessive breakage of rock beyond the desired excavation limit.

OVERBURDEN. -Worthless material lying on top of a deposit of useful materials. Overburden often refers to dirt or gravel, but can be rock, such as shale over limestone or shale and limestone over coal.

OVERDRIVE. -The act of inducing a velocity higher than the steady state velocity in a powder column by the use of a powerful primer. Overdrive is a temporary phenomenon and the powder quickly assumes its steady state velocity.

OXIDES OF NITROGEN. -See nitrogen oxides.

OXIDIZER. -An ingredient in an explosive or blasting agent which supplies oxygen to combine with the fuel to form gaseous or solid products of detonation. Ammonium nitrate is the most common oxidizer used in commercial explosives.

OXYGEN BALANCE. -A state of equilibrium in a mixture of fuels and oxidizers at which the gaseous products of detonation are predominately carbon dioxide, water vapor (steam), and free nitrogen. A mixture containing excess oxygen has a positive oxygen balance. One with excess fuel has a negative oxygen balance.

PARALLEL CIRCUIT. -A circuit in which two wires, called bus wires, extended from the lead wire. One leg wire from each cap in the circuit is hooked to each of the bus wires.

PARALLEL HOLE CUT. -A group of parallel holes, some of which are loaded with explosives, used to establish a free face in tunnel or heading blasting. One or more of the unloaded holes may be larger than the blastholes. Also called Coromant, Cornish, burn, shatter, or Michigan cut.

PARALLEL SERIES CIRCUIT. -Similar to a parallel circuit, but involving two or more series of electric blasting caps. One end of each series of caps is connected to each of the bus wires. Sometimes called series-in-parallel circuit.

PARTICLE VELOCITY. -A measure of ground vibration. Describes the velocity at which a particle of ground vibrates when excited by a seismic wave.

PATTERN. -A plan of holes laid out on a face or bench which are to be drilled for blasting. Burden and spacing dimensions are usually expressed in feet.

PELLET POWDER. -Black powder pressed into 2-in-long, 1¼-in to 2-in diameter cylindrical pellets.

PENTAERYTHRITOLTETRANITRATE (PETN). -A military explosive compound used as the core load of detonating cord and the base charge of blasting caps.

PENTOLITE. -A mixture of PETN and TNT which, when cast, is used as a cast primer.

PERMISSIBLE. -A machine, material, apparatus, or device that has been investigated, tested and approved by the Bureau of Mines or MSHA, and is maintained in permissible condition (MSHA).

PERMISSIBLE BLASTING. -Blasting according to MSHA regulations for underground coal mines or other gassy underground mines.

PERMISSIBLE EXPLOSIVES. -Explosives that have been approved by MSHA for use in underground coal mines or other gassy mines.

PETN. -See pentaerythritoltetranitrate.

PLACARDS. -Signs placed on vehicles transporting hazardous materials, including explosives, indicating the nature of the cargo.

PLASTER SHOT. -See mud cap.

PNEUMATIC LOADER. -One of a variety of machines, powered by compressed air, used to load blasting agents or cartridged water gels.

POWDER. -Any solid explosive.

POWDER CHEST. -A substantial, nonconductive portable container equipped with a lid and used at blasting sites for temporary storage of explosives.

POWDER FACTOR. -A ratio between the amount of powder loaded and the amount of rock broken, usually expressed as pounds per ton or pounds per cubic yard. In some cases, the reciprocals of these terms are used.

PREBLAST SURVEY. -A documentation of the existing condition of a structure. The survey is used to determine whether subsequent blasting causes damage to the structure.

PREMATURE. -A charge that detonates before it is intended. Prematures can be hazardous.

PRESHEARING. -See presplitting.

PRESPLITTING. -A form of controlled blasting in which decoupled charges are fired in closely spaced holes at the perimeter of the excavation. A presplit blast is fired before the main blast. Also called preshearing.

PRESSURE VESSEL. -A system for loading AN-FO into small diameter blastholes. The AN-FO is contained in a sealed vessel, to which air pressure is applied, forcing the AN-FO through a semiconductive hose and into the blasthole. Also known as a pressure pot.

PRILL. -In blasting, a small porous sphere of ammonium nitrate capable of absorbing more than 6 pct. by weight of fuel oil. Blasting prills have a bulk density of 0.80 to 0.85 g/cu cm.

PRIMARY BLAST. -The main blast executed to sustain production.

PRIMARY EXPLOSIVE. -An explosive or explosive mixture, sensitive to spark, flame, impact or friction, used in a detonator to initiate the explosion.

PRIMER. -A unit, package, or cartridge of cap sensitive explosive used to initiate other explosives or blasting agents and which contains a detonator (MSHA).

PROPAGATION. -The detonation of explosive charges by an impulse from a nearby explosive charge.

PROPAGATION BLASTING. -The use of closely spaced, sensitive charges. The shock from the first charge propagates through the ground, setting off the adjacent charge, and so on. Only one detonator is required. Primarily used for ditching in damp ground.

PROPELLANT EXPLOSIVE. -An explosive that normally deflagrates and is used for propulsion.

PULL. -The quantity of rock or length of advance excavated by a blast round.

RADIOFREQUENCY ENERGY. -Electrical energy traveling through the air as radio or electromagnetic waves. Under ideal conditions, this energy can fire an electric blasting cap. IME Pamphlet No. 20 recommends safe distances from transmitters to electric blasting caps.

RADIOFREQUENCY TRANSMITTER. -An electric device, such as a stationary or mobile radio transmitting station, which transmits a radiofrequency wave.

RDX. -Cyclotrimethylenetrinitramine, an explosive substance used in the manufacture of compositions B, C-3 and C-4. Composition B is useful as a cast primer.

RELIEVERS. -In a heading round, holes adjacent to the cut holes, used to expand the opening made by the cut holes.

RIB HOLES. -The holes at the sides of a tunnel or drift round, which determine the width of the opening.

RIP RAP. -Coarse rocks used for river bank or dam stabilization to reduce erosion by water flow.

ROTATIONAL FIRING. -A delay blasting system in which each charge successively displaces its burden into a void created by an explosive detonated on an earlier delay period.

ROUND. -A group or set of blastholes required to produce a unit of advance in underground headings or tunnels.

SAFETY FUSE. -A core of potassium nitrate black powder, enclosed in a covering of textile and waterproofing, which is used to initiate a blasting cap or a black powder charge. Safety fuse burns at a continuous, uniform rate.

SCALED DISTANCE. -A ratio used to predict ground vibrations. As commonly used in blasting, scaled distance equals the distance from the blast to the point of concern, in feet, divided by the square root of the charge weight of explosive per delay, in pounds. Normally, when using the equation, the delay period must be at least 9 ms.

SECONDARY BLASTING. -Using explosives to break boulders or high bottom resulting from the primary blast.

SEISMOGRAPH. -An instrument that measures and may supply a permanent record of earthborne vibrations induced by earthquakes or blasting.

SEMICONDUCTIVE HOSE. -A hose, used for pneumatic loading of AN-FO, which has a minimum electrical resistance of 1,000 ohms/ft and 10,000 ohms total resistance and a maximum total resistance of 2,000,000 ohms.

SENSITIVENESS. -A measure of an explosive's ability to propagate a detonation.

SENSITIVITY. -A measure of an explosive's susceptibility to detonation upon receiving an external impulse such as impact, shock, flame, or friction.

SENSITIZER. -An ingredient used in explosive compounds to promote greater ease in initiation or propagation of the detonation reaction.

SEQUENTIAL BLASTING MACHINE. -A series of condenser discharge blasting machines in a single unit which can be activated at various accurately timed intervals following the application of electrical current.

SERIES CIRCUIT. -A circuit of electric blasting caps in which each leg wire of a cap is connected to a leg wire from the adjacent caps so that the electrical current follows a single path through the entire circuit.

SERIES-IN-PARALLEL CIRCUIT. -See parallel series circuit.

SHATTER CUT. -See parallel hole cut.

SHELF LIFE. -The length of time for which an explosive can be stored without losing its efficient performance characteristics.

SHOCK ENERGY. -The shattering force of an explosive caused by the detonation wave.

SHOCK TUBE SYSTEM. -A system for initiating caps in which the energy is transmitted to the cap by means of a shock wave inside a hollow plastic tube.

SHOCK WAVE. -A pressure pulse that propagates at supersonic velocity.

SHOT. -See blast.

SHOT FIRER. -Also referred to as the shooter. The person who actually fires a blast. A powderman, on the other hand, may charge or load blastholes with explosives but may not fire the blast.

SHUNT. -A piece of metal or metal foil which short circuits the ends of cap leg wires to prevent stray currents from causing accidental detonation of the cap.

SILVER CHLORIDE CELL. -A low-current cell used in a blasting galvanometer and other devices used to measure continuity in electric blasting caps and circuits.

SLURRY. -An aqueous solution of ammonium nitrate, sensitized with a fuel, thickened, and crosslinked to provide a gelatinous consistency. Sometimes called a water gel. DOT may classify a slurry as a Class A explosive, a Class B explosive, or a blasting agent. An explosive or blasting agent containing substantial portions of water (MSHA). See emulsion; water gel.

SMOOTH BLASTING. -A method of controlled blasting, used underground, in which a series of closely spaced holes is drilled at the perimeter, loaded with decoupled charges, and fired on the highest delay period of the blast round.

SNAKE HOLE. -A borehole drilled slightly downward from horizontal into the floor of a quarry face. Also, a hole drilled under a boulder.

SODIUM NITRATE. -An oxidizer used in dynamites and sometimes in blasting agents.

SPACING. -The distance between boreholes or charges in a row, measured perpendicular to the burden and parallel to the free face of expected rock movement.

SPECIFIC GRAVITY. -The ratio of the weight of a given volume of any substance to the weight of an equal volume of water.

SPLITTER CORD. -See Ignitacord.

SPRINGING. -See chambering.

SQUARE PATTERN. -A pattern of blastholes in which the holes in succeeding rows are drilled directly behind the holes in the front row. In a truly square pattern the burden and spacing are equal.

SQUIB. -A fire device that burns with a flash. Used to ignite black powder or pellet powder.

STABILITY. -The ability of an explosive material to maintain its physical and chemical properties over a period of time in storage.

STAGGERED PATTERN. -A pattern of blastholes in which holes in each row are drilled between the holes in the preceding row.

STATIC ELECTRICITY. -Electrical energy stored on a person or object in a manner similar to that of a capacitor. Static electricity may be discharged into electrical initiators, thereby detonating them.

STEADY STATE VELOCITY. -The characteristic velocity at which a specific velocity, under specific conditions, in a given charge diameter, will detonate.

STEMMING. -The inert material, such as drill cuttings, used in the collar portion (or elsewhere) of a blasthole to confine the gaseous products of detonation. Also, the length of blasthole left uncharged.

STICK COUNT. -See cartridge count.

STRAY CURRENT. -Current flowing outside its normal conductor. A result of defective insulation, it may come from electrical equipment, electrified fences, electric railways, or similar items. Flow is facilitated by conductive paths such as pipelines and wet ground or other wet materials. Galvanic action of two dissimilar metals, in contact or connected by a conductor, may cause stray current.

STRENGTH. -A property of an explosive described in various terms such as cartridge or weight strength, seismic strength, shock or bubble energy, crater strength, ballistic mortar strength, etc. Not a well-defined property. Used to express an explosive's capacity to do work.

STRING LOADING. -The procedure of loading cartridges end to end in a borehole without deforming them. Used mainly in controlled blasting and permissible blasting.

SUBDRILL. -To drill blastholes beyond the planned grade lines or below floor level to insure breakage to the planned grade or floor level.

SUBSONIC. -Slower than the speed of sound.

SUPERSONIC. -Faster than the speed of sound.

SWELL FACTOR. -The ratio of the volume of a material in its solid state to that when broken. May also be expressed as the reciprocal of this number.

SYMPATHETIC PROPAGATION (SYMPATHETIC DETONATION). - Detonation of an explosive material by means of an impulse from another detonation through air, earth or water.

TAMPING. -The process of compressing the stemming or explosive in a blasthole. Sometimes used synonymously with stemming.

TAMPING BAG. -A cylindrical bag containing stemming material, used to confine explosive charges in boreholes.

TAMPING POLE. -See loading pole.

TEST BLASTING CAP NO. 8. -A detonator containing 0.40 to 0.45 g of PETN base charge at a specific gravity of 1.4 g/cu cm, and primed with standard weights of primer, depending on the manufacturer.

TOE. -The burden or distance between the bottom of a borehole and the vertical free face of a bench in an excavation. Also the rock left unbroken at the foot of a quarry blast.

TRANSIENT VELOCITY. -A velocity, different from the steady state velocity, which a primer imparts to a column of powder.

TRINITROTOLUENE (TNT). -A military explosive compound used industrially as a sensitizer for slurries and as an ingredient in pentolite and composition B. Once used as a free-running pelletized powder.

TRUNKLINE. -A detonating cord line used to connect the downlines or other detonating cord lines in a blast pattern. Usually runs along each row of blastholes.

TUNNEL. -A horizontal underground passage.

TWO-COMPONENT EXPLOSIVE. -See binary explosive.

UNCONFINED DETONATION VELOCITY. -The detonation velocity of an explosive material not confined by a borehole or other confined medium.

V-CUT. -A cut employing several pairs of angled holes, meeting at the bottoms, used to create free faces for the rest of the blast round.

VELOCITY. -The rate at which the detonation wave travels through an explosive. May be measured confined or unconfined. Manufacturer's data are sometimes measured with explosives confined in a steel pipe.

VENTURI LOADER. -See jet loader.

VOLUME STRENGTH. -See cartridge strength or bulk strength.

WATER GEL. -An aqueous solution of ammonium nitrate, sensitized with a fuel, thickened, and crosslinked to provide a gelatinous consistency. Also called a slurry. May be an explosive or a blasting agent.

WATER RESISTANCE. -A qualitative measure of the ability of an explosive or blasting agent to withstand exposure of water without becoming deteriorated or desensitized.

WATER STEMMING BAGS. -Plastic bags containing a self-sealing device, which are filled with water. Classified as a permissible stemming device by MSHA.

WEIGHT STRENGTH. -A rating that compares the strength of a given weight of explosive with an equivalent weight of straight nitroglycerin dynamite, or other explosive standard, expressed as a percentage.

APPENDIX 'D'

BIBLIOGRAPHY

BIBLIOGRAPHY

Recommended publications:

1. U.S. Government: Laws and Regulations:

Public Law 95-87 (30 USC 1201 et seq.)

30 CFR 816 et seq.

2. U.S. Department of the Interior, Bureau of Mines:

Bulletin 656: "Blasting Vibrations and Their Effects on Structures", 1971. Harry R. Nicholls, Charles F. Johnson and Wilbur I. Duvall.

Information Circular 8925: "Explosives and Blasting Procedures Manual", 1983. Richard A. Dick, Larry R. Fletcher, and Dennis V. D'Andrea.

Report of Investigations 8485: "Structure Response and Damage Produced by Airblast From Surface Mining", 1980. David E. Siskind, Virgil J. Stachura, Mark S. Stagg and John W. Kopp.

Report of Investigations 8506: "Measurement of Blast Induced Ground Vibrations and Seismograph Calibration", 1980. Mark S. Stagg and Alvin J. Engler.

Report of Investigations 8507: "Structure Response and Damage Produced by Ground Vibration From Surface Mine Blasting", 1980. David E. Siskind, M.S. Stagg, J.W. Kopp, and C.H. Dowding.

Report of Investigations 8508: "Airblast Instrumentation and Measurement Techniques for Surface Mine Blasting", 1981. Virgil J. Stachura, David E. Siskind and Alvin J. Engler.

Report of Investigations 8896: "Effects of Repeated Blasting on a Wood-Frame House", 1984. Mark S. Stagg, David E. Siskind, Michael G. Stevens and Charles H. Dowding.

3. ATF P 5400.7 (11/82): "ATF : Explosives Law and Regulations", 1982.

4. Independent publications and reports:

"Blaster's Handbook" 16th Edition, 1980. Explosives Products Division, E.I. Du Pont de Nemours & Co., (Inc.), Wilmington, Delaware, 19898.

"Blaster's Handbook" 6th Edition, 1968. Canadian Industries Limited, Explosives Division, Montreal, Quebec, Canada.

"Blasting Operations", Gary B. Hemphill, 1981. McGraw-Hill Inc.

"Blasting Technique", Rune Gustafsson, 1981. Dynamit-Nobel, Wien.

"Blast Vibration Analysis", G.A. Bollinger, 1971. Southern Illinois University Press, Carbondale, Illinois, 62901.

"Blast Vibration Monitoring & Control", C.H. Dowding, 1985. Prentice-Hall, Englewood Cliffs, N.J.

"Control of Vibration and Blast Noise from Surface Coal Mining." Vols. I to IV, December 1978. Wiss, Janney, Elstner and Associates, Inc, Northbrook, IL. Report to USBM, Contract No. J0255022. NTIS PB-299 887.

"The Development of Rational Damage Criteria for Low-Rise Structures Subjected to Blasting Vibrations", August 1976. Kenneth Medearis (Kenneth Medearis Associates), Final Report to Crushed Stone Association, Washington, D.C.

Bibliography

"Geologic Factors Affecting Vibration from Surface Mine Blasting", Final Report to USBM, Twin Cities. Contract H.0222009: September 1985. Vibra-Tech Engineers, Hazleton, Pennsylvania.

"The Modern Technique of Rock Blasting", U. Langefors & B.A. Kihlstrom, 1963. John Wiley & Sons, Inc. N.Y.

5. Citizen Interests:

"Blasting Damage - A Guide for Adjusters & Engineers", 2nd Edition, 1972. Claims Bureau, Engineering and Safety Service and Property Claim Services of American Insurance Association.

"Strip Mine Blasting", Albert Fritsch, Dennis Darcey, Gerard McMahon, Elaine Burns & Brian Ulrickson, 1977. Center for Science in the Public Interest, Washington, D.C.

"Citizens' Blasting Handbook", Mark L. Morgan, Edwin A. Moss & Albert J. Fritsch, 1978. Appalachia-Science in the Public Interest, Corbin, KY.

☆U.S. GOVERNMENT PRINTING OFFICE: 1987 774-613/65093