OPEN FILE REPORT

Supplimentary Information for Bureau of Mines Study on Response and Damage Produced by Ground Vibrations From Blasting, RI 8507

By D. E. Siskind

Review Comments

UNITED STATES DEPARTMENT OF THE INTERIOR
James Watt, Secretary

BUREAU OF MINES
Hermann Enzer, Acting Director

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United States Department of the Interior

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March 4, 1981

Memorandum

To: Donald E. Ralston, Chief, Branch of Technology Transfer, Division of Minerals Health and Safety Technology

Through: Donald G. Rogich, Director, Division of Research Center Operations, Washington, D.C.
David R. Forshey, Director, Division of Minerals Environmental Technology, Washington, D.C.
John W. Corwine, Research Director, TCRC
Dennis V. D'Andrea, Research Supervisor, Blasting Technology and In Situ Mining, TCRC

From: David E. Siskind, Group Supervisor, Blasting Technology, TCRC

Subject: Approval Request for Open Filing of "Supplimentary Information for Bureau of Mines Sudy on Response and Damage Produced by Ground Vibrations from Blasting, RI 8507"

A presentation was made of the Bureau of Mines research reported in RI 8507 at the meeting of the National Crushed Stone Association in New Orleans, January 13, 1981. At that time, questions were raised about the availability of the raw data used for the analyses and also some additional plots. Dr. Lindsey Norman was in attendance and suggested that this material be made available on open file.

As a result, the subject draft OFR has been prepared. In addition to the two above items, the report contains the 55 most significant review comments made about RI 8507, replies to these comments, and an errata sheet.

I request that this report be placed on open file at the major Bureau of Mines Centers and libraries and also made available through NTIS.

Enclosed are four copies of the report.

David E. Siskind
DAVID E. SISKIND

Enclosures

cc: D. D'Andrea
R. Dick
C. Dowding

INTRODUCTION

The Bureau of Mines completed a study of blast-produced vibration damage and response of residential structures from blasting and published a Report of Investigations 8507 in December 1980. In addition to the RI itself, the research results were discussed in six presentations between October 1980 and January 1981.

Many significant suggestions and comments were made by various industry and government spokesman as a result of the technical review of the manuscript and the six talks. These suggestions were incorporated into the RI manuscript, where it was appropriate and practical to do so. Some of the comments included claims of serious economic, social and legal impact and disruption. Because these claims require a rather extensive analysis and discussion, a report specifically on these problems was prepared as an Information Circular, "Blasting Vibrations and its Control, Technical, Legal, Social and Economic Impact", by the author, A.J. Engler and M. Radnor.

In short, the claimed adverse impact of the RI are without foundation. By contrast many of the vibration problems faced by the mining and other blasting industries between 1975 and 1980 were caused by the absence of realistic environmental and design criteria for both airblast and ground vibration.

All of the comments required some kind of a reply and, in a few cases, indicated a need for additional data processing and plotting. Space limitations in RI 8507 made it inpractical to analyze and include all permutations and combinations of the 10 sets of damage data; however, it was later concluded that at least three additional runs were justified. Noteworthy is that these analyses which included in this OFR do not justify changing any of the original conclusions in RI 8507.

This Open File Report was prepared at the suggestion of Dr. Lindsey D. Norman. Dr. Norman was in attendance at a presentation of the Bureau's vibration research at the January 1981 meeting of the National Crushed Stone Association. There had been some discussions of the analysis problems claimed for RI 8507 and the additional data runs that had been made to satisfy these claims. These new results are consistant with those presented in RI 8507. However, where further study is required or regulatory proposals are to be based on a variation of the analyses in RI 8507, the tables and plots in this OFR may be useful. Finally, it is appropriate that the many review comments and associated replies for RI 8507 be made available to assist potential users of the report in judging the material for its own merit.

REVIEW COMMENTS FOR RI 8507

This section contains 55 major review comments and replies pertaining to the RI manuscript which were received between February 1980 and January 1981. All unfavorable comments are included, but only a sampling of those that were favorable. Following the comments is a listing of commenters. Several reviewers of the paper had no major criticisms, and are not included. The list of reviewers includes 7 from industry, 2 from government (or retired), 1 from a university, and 1 from a environmental public interest group. The comments, of course, reflect this make up.

Noteworthy is that three reviewers, Alan Foster, Gerald Coonan, and Edward Walter were selected by the National Coal Board to review the RI draft. Finally, two of the reviewers, Harry Nicholls and Wilber Duvall, are the remaining living authors of Bulletin 656, the previous comprehensive publication on blasting vibrations.

RI 8507 - STRUCTURE RESPONSE AND DAMAGE PRODUCED BY GROUND VIBRATION FROM SURFACE MINE BLASTING

MAJOR REVIEW COMMENTS

1) COMMENT: Why discuss wave train lengths, e.g., longer than 2 seconds? (AA)

REPLY: We were interested in some kind of separation of steady state (or long duration isolated events) and transients such as blasting. An important result of this report is to separate mine blasting effects from those produced by earthquakes and nuclear blasts. There is probably a direct correlation between wave train length and annoyance (as well as fatigue).

2) COMMENT: Use of lines as well as points in probability plots is confusing and open to misuse. (AA)

REPLY: The mean regression lines show how well the various data sets fit the theoretical log-normal distribution. Following our statistician's suggestion, we have recommended the use of points rather than lines for prediction purposes.

3) COMMENT: Frequency-dependent safe levels are confusing and unworkable. Need a weighting function. (AA)

REPLY: This is the problem of implementation. A weighting scale is possible, or one with dual peak-hold readouts. Weightings require RMS systems (not peak, because of phase distortions). For coal or large scale quarry blasting, could just try to meet 0.75 in/s criteria. Construction blasting is a future problem. Other implementation options exist, such as the current Swedish technique of simultaneous velocity and displacement assessment.

4) COMMENT: Very interesting, comprehensive, technically sound, practical, and objective. (WD)

REPLY: None needed.

5) COMMENT: Damage criteria are based on low frequencies (e.g., coal mine blasts). May be too restrictive for hard rock surface mine blasting or quarrying. (WD)

REPLY: Following this criticism, an additional section was written which covers the intermediate frequencies between 15 and 40 Hz (Appendix B). This scheme also has two additional benefits of showing displacement-bound condition when blast frequencies are less than structure response frequencies, and also shows that nuclear blasts and earthquakes are clearly different problems than blasting, and more serious because of their low frequencies.

6) COMMENT: Damage analysis should be rerun without shaker data. (CD)

REPLY: This was done, with no significant difference. The 5 pct probability value is 0.56 in/s instead of 0.52 in/s. Criteria in RI 8507 is still 0.75 in/sec. The type of excitation and observations made for the shaker tests were similar enough to blasting to justify their use, as judged by the authors of Bulletin 656 as well as this report.

7) COMMENT: Weren't measurements made in different places in the various old studies? (CD)

REPLY: This variable is obviously not controllable by the current authors. Two factors work in favor of minimizing this problem. It was expected that a large enough quantity of data would minimize the detrimental effects of the scatter (e.g., improve statistical predictability). Additionally, many of the measurements were not too dissimilar from the expected ideal, for instance, mid-foundation wall vibrations will approximate those from buried gages as long as there is no differential motion. Assumptions and approximations that were made in the study are discussed in the report.

8) COMMENT: "The need for a criterion which is simply measured, and then simply understood, is as strong today as it was in 1971. I am pleased that particle velocity is still recommended." (HN)

REPLY: None needed.

9) COMMENT: "A probabilistic approach is the best. We still have damage at unexplainable vibration levels." (HN)

REPLY: None needed.

10) COMMENT: Why are the conclusions radically different than Bulletin 656 when 8 of the existing studies were known to the authors of B-656? (AF)

REPLY: B-656 damage analyis goes back to 1962 (RI 5968), not 1971. No attempt was made in 1971 to redo the damage analysis. The objection to Dvorak's data is weak (displacement seismograph was same as used by Langefors), and the Northwood, et al. 1963 study wasn't added. The two remaining authors of B-656 reviewed RI 8607 and did not object to use of the additional studies, in fact approved it. Finally, the low-frequency criterion in RI 8507 is not significantly based on Dvorak.

11) COMMENT: Isn't there little new damage data, and isn't it mostly low frequency? (AF)

REPLY: Most homes were occupied and the vibration levels held down to prevent damage. Equally as valuable as the damage data was the response data. Difference in frequency shows up strongly in response as well as damage, and is well supported by data. There is much more data now than was available for B-656. A strong point is made in RI 8507 that low frequency vibrations are the most serious, based on both response and damage analyses and years of industry experience.

12) COMMENT: Aren't these criteria useless? ". . . we have to defend and justify the damage criteria used by the blasting industry. We require cirteria which are based on the best available data which will protect both the interests on the general public and the blasting industry." (AF)

REPLY: Are you planning to continue using B-656, and hiding behind it? Since it isn't considered practical today, what do you propose as an alternative, Sparta-Peabody, DIN, Nadolski, etc?

It is felt by the authors, most of the reviewers, and many in government and industry that the recommendations made in RI 8507 are reasonable technically justifiable, consistent with most current practice and long overdue. In fact, they are more liberal than most other vibrations criteria published since 1962, despite being lower than previous Bureau of Mines recommendations. Much of the effort represented by RI 8507 was toward showing why the overwhelming hue and cry for ultra-strict vibration criteria is unjustified. The recommendations in RI 8507 serve the public interest by establishing realistic and workable blasting criteria. They will provide protection for both the mining industry and the public. As to the cost, the increased blasting costs quoted are not only exaggerated, but for most companies, totally nonexistent. Specific studies of the cost, impact, and current practices have shown that relatively few operations will have to redesign, and for those that do, the cost is minor.

13) COMMENT: Isn't more data needed? (AF)

REPLY: Of course, but how long should we wait? RI 8507 isn't the last word, only the latest. Fatigue studies or those on human response may later lead to lower appropriate levels. Precedents such as made for purposes of obtaining permits will lead to tighter restrictions in the absence of new Bureau recommendations. Hundreds of requests for assistance demonstrate that industry and government are in need of guidelines now. Rather than being premature, the report is overdue.

14) COMMENT: Why wasn't the BM data analyzed alone? (AF)

REPLY: Not all combinations of the 10 data sets were run as it would have yielded too many figures to use. Out of curiosity, the probability plots of BM new data was run and it was similar to those already shown. It strongly justified the 0.75 in/s low-frequency criteria.

15) COMMENT: Wasn't the furnace removed from one of the study structures, and also wallpaper scraped off? (AF)

REPLY: Yes. This may have contributed to the weakening. However, observed damage was correlated to specific blasts. The removal of wallpaper itself did not seem to cause damage. None of the studies were run in the winter when the absence of heat would have been most detrimental. Since we are most concerned with thresholds rather than mean levels for damage, the condition of the structure isn't critical.

16) COMMENT: Why do you think that response spectra aren't useful for assessment of damage potential? (AF)

REPLY: The SDF response spectra model characterizes the time history, but assumes a model for response which is too simple. Not enough SDF vs damage data exists and what does exist did not improve predictions over using a simple PPV criteria over two frequency ranges. Dowding's SDF analyses of our damage data weren't an improvement over simple peak value. Medearis' analysis, weak as it is, produced values for peak particle velocity quite similiar to RI 8507. Once response characteristics were established for residences (responses of limited scope), a simple peak value criteria is possible. A SDF criteria may never exist, particularly as most blasters and consultants "never see blast damage."

17) COMMENT: Isn't the 40 Hz gross frequency meaningless in terms of structural response? (AF)

REPLY: Not at all.
1. Determined from corner and midwall responses and amplification factors.
2. Separates the high and low frequecy damage data (by sets).
3. A 40 Hz turning point was also found by the Swedes in a 1980 report given at the Rock Store conference in Stockhom.
4. Resulting displacement criteria are consistent with both old U.S. and current U.K. practices.

18) COMMENT: Isn't most human response data from steady state tests? Why use Peak Particle Velocity? (AF)

REPLY: Yes, most previous publications had discussed responses from steady state vibrations. The recommended 0.5 in/s (95%) in RI 8507 is based on transients of less than 1 second duration. This is probably an upper value. The psychological factors will undoubtedly suggest lower values, but can be modified by good blaster-neighbor relations. Peak particle velocities correlated best for Wiss' and Murray's analyses (up to 25 Hz). Results were very consistent with other studies, for instance sonic boom annoyance tests. We can't wait for the new study which may not be completed until 1983. Steady state data is already being applied to blasting.

19) COMMENT: Quoted working norms (U.K.). They are not based on damage. Why mention them? (AF)

REPLY: No claims were made of the validity or background of the criteria tables of Appendix A. When those numbers were derived (made up, fanticized, pulled out of thin air), there must have been some reason to suspect that they are somehow useful and practical. If we discard B-656 and RI 8507, we'll eventually see such norms in the U.S. The Swedish Data are backed up by measurements. The other sources are discussed in the RI.

20) COMMENT: Isn't the Woodward Clyde damage data doubtful? (AF)

REPLY: One point was, with a blast to structure distance of 5 ft. It wasn't used. (Probably permanent ground strain). There is no reason to doubt any of the remaining data.

21) COMMENT: Weren't you working toward a predetermined criteria? (AF)

REPLY: No. RI 8507 recommendations do not support OSM or any other particular standards. Quite to the contrary, where doubt existed, compromises tended to be made to the benefit of industry.

22)COMMENT: Aren't 202 of the 228 damage points from old, unverifiable studies, and hence useless? (AF)

REPLY: They are unverifiable in that the time histories are lost and it isn't possible to redo the experiments. However, there is little justification in dismissing the old data offhand. If so, then B-656 is useless, as it uses all "old unverifiable" data. Until now, the industry did not seem to mind using 656 in their court cases. What will they use in the future? The problems with the old studies are discussed in the text of RI 8507. While it isn't possible to redo the old experiments, nor recover the lost time histories, it isn't reasonable to label them "useless." As discussed in RI 8507, the various authors are taken at their word and their data are assumed reliable unless their work clearly seems unapplicable. Incidently, the new BuMines data alone supports an 0.75 in/s safe vibration criteria.

23)COMMENT: Some studies (from Table 9) involved records of motion in units other than particle velocitiy. Conversion to velocity aren't accurate. "Thus 6 of the 10 studies are suspect. (GC)

REPLY: Original mean and variance analyses were based on displacements (as RI 5968, B656). Conversion by simple harmonic motion assumptions is approximate but reasonable (as shown in RI 7939) particularly for the low frequency end of the wave trains.

24)COMMENT: Number of damage and non-damage shots for new BM data in Table 9 doesn't agree with figures 46 and 47. (GC)

REPLY: Table 9 is correct and based on number of shots. Figures 46 and 47 are number of independent observations. For statistical analyses, the numbers in Table 9 were used. The actual number of non-damage points is well in excess of Table 9 and Figure 47. The number of non-damage points in figure 47 is arbitrary, depending on the low velocity cutoff. Obviously there are many non-damage observations at low levels which are not included.

25)COMMENT: Inconsistencies with low frequency and summary plots. Want to be able to accurately track the new BuMines data . . . and check the validity of these points. (GC)

REPLY: Problem with Dvorak was recognized, hence we analyzed sets 4 and 5. Following the publication of 8507, ran BOM data separately and also all low frequency data without the shaker damage data. Same results. See comments 6 and 14.

26)COMMENT: Is the damage probability of plaster walls with wallpaper the same as drywall? (GC)

REPLY: Did not test this. The wallpaper's contribution to the strength of the plaster would likely be less than the paper on wallboard. However, like wallboard paper, it can conceal damage.

27)COMMENT: "Percentages annoyed" recommendations are too preliminary. "Don't think that fear of damage and startle effects have been adequately evaluated in this report." (GC)

REPLY: Correct. This has been done for sonic booms (Borsky), but not directly for ground vibrations. Will undoubtedly increase reactions of population. As pointed out in RI 8507, vibration tolerances of 95 pct at 0.50 in/sec for short events will be decreased to possibly 70 pct because of damage fear and startle effects. The effectivensss of the mine's public relations efforts will determine the specific local reactions within these extremes.

28)COMMENT: RI 8507 claims that complaints at low levels (less than 0.50 in/s) are attributable to low frequencies. Verify or reference. (GC)

REPLY: Specific comment on complaints was deleted. However, discussion of Salmon and other low frequency cases (earthquakes, large blasts, and other nuclear blasts) establishes the special seriousness of this problem (p. 6 to 8, p. 62). Also recall the Dade County quarry blasting situation of 1979 with low frequencies and long durations.

29)COMMENT: RI 8507 claims that coal mine vibration levels are higher than quarry at large scaled distances. (GC)

REPLY: See figures 11 or 12, or compare figures 6 to 9 of RI 8507 and 6.2 of B-656.

30)COMMENT: Frequency, dominant or peak. Which was used for amplification factors? (GC)

REPLY: Frequencies were correlated to observed peaks and responses with time considerations (e.g., correlated in time). Where distinct responses or frequencies could not be identified, the results were not used for response analysis.

31)COMMENT: Peabody Eagle Mine data points. Aren't some questionable? (GC)

REPLY: The 0.72 in/s damage point is legitimate. However, the values from shots 9 and 10 were omitted as an oversight (Shots 1-3, 5, 6 were questionable). Rerunning the data either without 0.72 (shot 11) or with 9 and 10 added made insignificant difference. Damage inspections were made of selected wall areas specifically prior to and following blasts 9, 10, and 11, even though there was less than 20 minutes between these shots.

32)COMMENT: RI 8507 claims that cracking potential is a function of corner motions. Didn't show this with damage data. (GC)

REPLY: Assumption was based on strain and reponse considerations and nature of crack patterns. Have since verified this assumption by direct strain measurements. More could have been done with response measurements, resources permitting. There currently exists only a small amount of good response-damage data (ours and Wiss').

33)COMMENT: "Excellent piece of work."(EW)
REPLY: None needed.

34)COMMENT: Problems with the definitions of damage. "Extensions of cracks and development of new cracks represent different states of stress." (EW)
REPLY: Adopted classifications most common to all previous studies. Impossible to separate these degrees of damage to building materials in situ.

35)COMMENT: "Little commonality found from experiment to experiment, and from investigator to investigator." (EW)
REPLY: Grouping of sets for analysis was made for maximum use of the commonality that did exist. Not as bad as RI 5968 (and Bulletin 656). Relied on quantity of data to improve the statistical reliability. See comments 7, 22, and 23.

36)COMMENT: Not much new low-frequency data, only 3 studies. "The 0.50 in/s (≪40 Hz) criterion should be approached with caution." (EW)
REPLY: Interpretations and criteria recommendations were made with reservations. They are more realistic and well founded than other recent reports, Nadolski '69, Jackson '67, Barnes 77, Medearis '76, and less restrictive than Peabody's Sparta, Ill. agreement of 0.2 in/s max (at as little as 1/2 mile). Basic recommendation for low-frequency blasting is a safe level criterion of 0.75 in/sec, not 0.50 in/sec. The lower value is intended as a viable alternative available for sensitive situations, such as done in current British and German practices.

37)COMMENT: Safe-level criteria for low frequencies did not err sufficiently on the side of caution. Should use 97 pct safe level of 0.32 in/sec from low-frequency data alone. (CS)
REPLY: The most significant low-frequency analyses are of sets 4 and 5. Set 4 justifies a criteria of 0.70 in/sec. Set 5 includes Dvorak's study and indicates a 95-pct safe criteria of 0.52 in/sec. Dvorak's data are enough suspect to make the lower value justified under conditions of high risk. The following factors also apply to this problem:

a) Vibration levels will always be distributed somewhat below the limits, probably 30 to 50 pct.

b) Homes are spacially distributed, with all others at a reduced risk relative to the closest structure.

c) The rapid roll-off of probability below 1.0 in/sec suggests that the level corresponding to a 95 pct safe condition also applies to a greater percentage, aproaching 100 pct. (Note the strong influence of the statistically maverick point included in sets 4 and 5, which was later omitted in the summary analysis, Set 7).

d) The lowest actual observed damage value for coal mine blasting is 0.72 in/sec in the new BuMines study. Without new data, such as fatigue or strain results, there is little justification for expecting the industry to meet a general vibration limit below 0.75 in/sec.

e) It is strongly felt by the authors that the 0.50 in/sec safe level criteria should be available as an alternative for regulatory authority in the event that greater-than-average protection is required.

38) COMMENT: Scaled distance recommendations are not high enough to prevent 0.5 in/sec from being generated. (CS)

REPLY: While it is the intent of scaled distance criteria to provide an ultimate safe condition for non-monitored blasting, in reality a finite data set must be used. Additionally, there are choices as to whose data set. The recommended square root scaled distnace of 70 (conclusion #3) is based on 0.75 in/s (not 0.50 in/s) from Fig. 10, using the maximum envelope of coal mine blast measurements within the scaled distance range of 10 to 400 ft/lbs$^{1/2}$. As discussed in the text, using Wiss' or Lucole's data or any given number of standard deviations will result in somewhat different scaled distance criteria. Where a 0.50 in/s peak particle velocity is required, a scaled distance of 90 ft/lbs$^{1/2}$ is appropriate. It is possible that the higher values from the Wiss' and particularly the Lucole study are from sites with greater propagation, or more likely that the pounds per delay criteria that is failing in some way. An alternative to scaled distance could be derived, taking frequency into consideration.

39) COMMENT: Annoyance criteria assumes good public relations program, which isn't generally the case. Should have lower criteria as the 15-30 pct annoyed is too high (in the absence of a public relations program). (CS)

REPLY: The problem of human annoyance from transient vibrations is still under study. A fair amount of data is available on direct tests on human subjects and the relative effects of transient and steady-state vibrations. The values of perception and response in figure 66 are based on physiological reactions, and are minimal responses (e.g. 5 pct unacceptable at 0.50 in/sec for 1 second duration vibration). The addition of fear of damage, startle, and fright will increase adverse reactions to up to 30 pct. To the degree that good public relations will allay these apprehensions and convince homeowners that the nearby mine wants to be a responsible neighbor, higher levels could be tolerable. See comment #27 for further reflection.

40) COMMENT: Fatigue knowledge is to rudimentary. (CS)

REPLY: This is correct, and additional effort is ongoing. The data available at this time is consistent with the criteria recommended in RI 8507, and has established that the non-engineered construction and materials used for residences do indeed exhibit classical fatigue failure characteristics.

41) COMMENT: RI 8507 includes technical data by other authors that the BuMines previously considered suspect or lacking in complete technical description. (DM)

REPLY: See comments 7, 22, 23, 35.

42) COMMENT: Some of the new Bureau of Mines damage presented in the report were gathered under circumstances not representative of the normal environment for residences. (DM)

REPLY: See comment 15.

43) COMMENT: A number of data plots appear to include such inconsistencies as to necessitate a review of the validity of the technical data. (DM)

REPLY: See comments 20, 25, 31, 34.

44) COMMENT: Reviewers of the report are not allowed to conduct even a rudimentary assessment of the validity of much of the data because the report does not include all the pertinent information the BuMines used in generating its report. (DM)

REPLY: It is not at all clear what is being stated here. Examination of field notes would not establish the validity of the observations. The study could be done over, as well as the other nine that were analyzed. Tapes are available if a reviewer wants to reexamine the 14,000 measurements. RI 8507 includes a complete list of structures and shots for the Bureau measurements and a table outlining the similarities and differences in the various studies analyzed. Previous reports, such as RI 5968 and B-656, did not include such detail and tended to down play their limitations. There is absolutely no justification that the report is deficient, and in fact is probably too long and detailed for easy practical reference. The same criticism applies to the companion airblast report, RI 8485.

45) COMMENT: There are cases where blasting vibration may be just one or a minor contribution to the damage or be just a proximate cause. Studies are needed on the states of damage in residences independent of blasting. (LO)

REPLY: This is recognized and discussed in RI 8507. There is no easy way, and possibly no way at all, to measure the existing state of strain in buildings. However, strain changes are easily measured. Measurements referenced to the initial strainless state (new house) can be used to quantify the strain-producing conditions, blasting and otherwise. This is precisely what is being done in the BOM/AMAX structural fatigue study. Extensive environmental monitoring is being made including weather, settlement, vibrations and human activities. Dynamic and static strains are being measured on both the superstructure and masonry. A complementary proposal involving inspections of many structures both near and far from blasting was not funded. This would have been a more objective version of the Barnes study.

46) COMMENT: There are no absolute safe levels. (LO)

REPLY: This is true, and is discussed in the report. It was also true for Bulletin 656 and RI 5968, although the statistical nature of the 2 in/sec-criterion is not widely appreciated. The practice of holding B-656 up to a jury or judge as proof of good and safe blasting, "We were following the federal guidelines", is no longer protection against claims which are now often considered on the basis of absolute liability. The 2 in/sec criterion was not absolutely safe, and neither are the new recommendations. However, the nature of the probability results suggests they represent safe levels to better than 95 pct.

47) COMMENT: House descriptions in RI 8507 were not complete. (LO)

REPLY: The 76 homes studied by the Bureau are described in a large table (No. 3), and the 15 most important structures shown in photographs (figures 15 to 28 and 42). It simply wasn't practical to give detailed floorplans, crack photographs, drawings, response time histories, and notes from this 4 years of work in a summary publication. This material is contained in four bookcases and will be kept available for future studies.

48) COMMENT: Conclusion Nos. 1 and 2 recommend the continued use of peak particle velocity, but not the frequency nor displacement characteristics. (IM)

REPLY: The question here involves the term "most practical" in conclusion 2. In many ways, particle velocity measurement is still the most practical. The frequency effects on response and the possible use of velocity within certain frequency bands is discussed throughout the report. Admittedly, frequency is not mentioned in the conclusions until No. 4. Conclusions 1 and 2 could have been combined and expanded to include both the simple case (particle velocities in frequency bands) and complex one (combinations of displacements and velocities). In a later publication of this work, e.g., a Bulletin, these minor problems can be rectified.

49) COMMENT: Scaled distance does not take frequency into consideration. The Bureau should re-examine their data to determine if a quantity-distance relationship other than scaled distance may be more appropriate. (IM)

REPLY: It is likely that no universal quantity-distance relationship could adequately quantify frequency, simply because of the strong influence of the material celerity (propagation velocity, related to strength through elastic constants and density). However, the analysis of existing data for some kind of improved prediction scheme is a viable and straightforward task. It would not require any additional field measurements, but a great amount of data handling. At the moment, there is no plan to do such a job due to limited resources and other committments. In addition, this conclusion may have been better placed if it followed those with the damage criteria and frequency considerations.

50)COMMENT: The drywall criteria is difficult to justify from the data presented. (IM)

REPLY: This is true. It is difficult to obtain modern homes for damage tests. The amount of drywall data alone was insufficient for a damage probability plot. However, the individual observations support the 0.75 in/sec as a minimum safe value, although this may be conservative. Currently ongoing research will greatly expand the understanding of the drywall situation and hopefully equate damage to strain. The engineering tests on drywall strength are also roughly consistent with the recommended levels.

51)COMMENT: The high frequency criteria of 2.0 in/sec is too conservative. Langefors and Kihlstrom recommend 2.8 in/sec. (IM)

REPLY: This may be true but there is too little good data to back it up. Many of the criticisms of Dvorak's study also apply to the old Swedish work, that of old techniques and old instrumentation. The little bit of modern damage data at high frequencies suggests that the Langefors recommendations may be too high. Proposed 1981 Swedish standards for safe vibration limits above 40 Hz are 50 mm/sec (2 in/sec).

52)COMMENT: Use of particle velocity in two bands separated by 40 Hz is too simplistic and create interpretation problems for complex waveforms. (IM) *

REPLY: A simple method is needed for some purposes and the velocity-displacement techniques (Appendix B of RI 8507) is probably not practical for the present. The envelopes of the damage data and also lines paralleling the means (at some number of standard deviations) can be pretty well approximated by two separate velocity values, with the 40 Hz as a reasonable separation. The response results also support this. The validity of such a technique is greater than the original overall frequency independent 2 in/sec criteria of Bulletin 656. The more complex displacement and velocity technique is preferred but may have to await new instrumentation. The 40 Hz problem is not too difficult. Most blasts, particularly mining, will be below 40 Hz. Other- wise, if in doubt, design for 0.75 in/sec. Some guidelines are given in the report for deciding the frequency content.

53)COMMENT: A filter should be built to reproduce the criteria curve of figure B-1 of RI 8507. (IM)

REPLY: This also occurred to us as well as other options for implementing the combination displacement and velocity criteria of Appendix B. At this moment, we do not have the resources to fund the design and testing of such a device; however, it would be a rather easy task for one of the seismograph companies. One problem may be with phase distortion and the resulting meaningless of a filtered peak value. It would be necessary to consider some kind of RMS criteria, instead of peak.

54) COMMENT: The Bureau should produce a summary Bulletin with specification and guidelines for measurement and other material currently in the four reports RI 8485, 8506, 8507, and 8508. (IM)

REPLY: Such a summary report is under consideration. It will also have to include, new results from the ongoing projects on fatigue and human response, and possibly some of the social, economic and legal findings from the Northwestern CISST study.

55) COMMENT: This report was pushed through review faster than any other Bureau of Mines publication, most likely because of pressure from OSM. (AF)

REPLY: This is totally false. The research began in 1975, long before the existance of OSM. The report was started on 7-23-79 and completed 12-25-79. It went to station review (1 official and 6 unofficial) 1-7-80 and all copies were back by 3-10-80. It then was rewritten and went to field review 5-14-80. After 4 official, 2 unofficial and 3 supplementary (NCA) field reviews, it was ready on 8-20-80 for Washington Office review and printing, a process that took an additional 3 1/2 months. It was at this last stage only that there was any upper-level assistance in completion of the report processing. The gestation period for this report was 11 1/2 months <u>after writing</u>, hardly record breaking. (16 reviews is somewhat more than the standard BuMines requirement) There were many reasons for the authors to try to expedite this report. Among them were:

1. Project funds had run out September 30, 1978.
2. Proposals by CHABA and ISO demonstrated immediate need for publication of the new Bureau results.
3. Need by State, local as well as Federal agencies (OSM, EPA, HUD, DOD) for realistic environmental criteria for impulse events.
4. Rumor that Dr. Cardon in Alabama was doing an analysis similar to the Bureau's, but on old data only.
5. Preparation of this report had been delayed almost 10 months because of another large manuscript, RI 8485 on airblast, that was started 10-1-78 and completed (sent to Washington) on 8-9-79.

KEY TO COMMENTERS

RI 8507

AA	Al Andrews, E.I. DuPont Co., Explosives Manufacturer
WD	Wilber Duvall, Retired from BuMines and self employed. Author of Bulletin 656.
CD	Chuck Dowding, NW University, Dept. of Civil Engineering
HN	Harry Nicholls, BuMines and author of Bulletin 656.
AF	Alan Foster, Vibra Tech Engineers, Inc.
GC	Gerald Coonan, Peabody Coal Co.
EW	Edward Walter, Consultant, Ohio
CS	Chuck Sheketoff, Illinois South Project
DM	Donald Matthews, Society of Explosives Engineers
LO	Lou Oriard, Society of Explosives Engineers
IM	Institute of Makers of Explosives

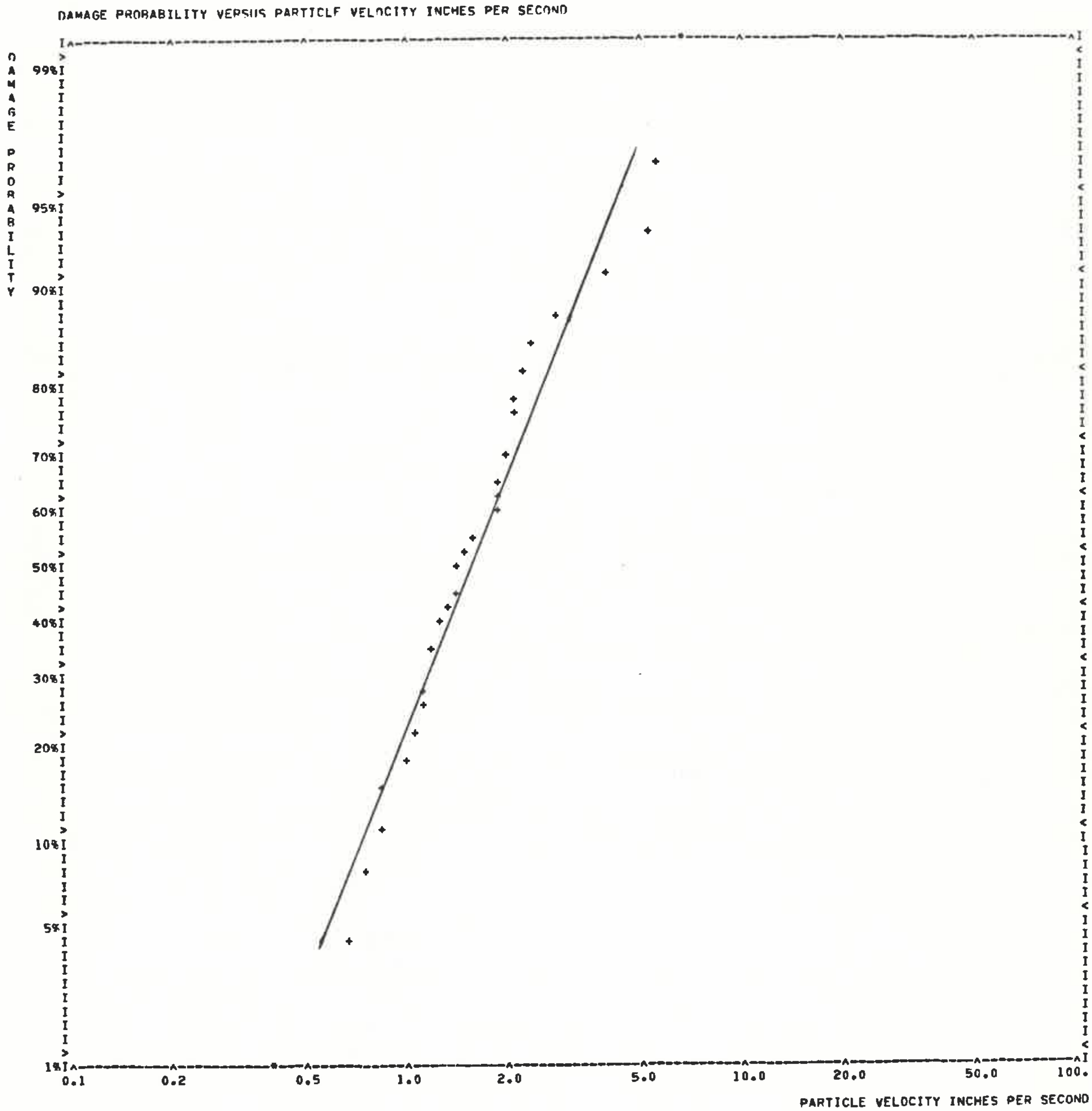
ADDITIONAL DAMAGE PROBABILITY PLOTS

Figures 1 to 3 show the results of 3 additional probability damage runs, similar to those in RI 8507 (figs. 55-59). The first new analysis (fig. 2) was run to determine what would emerge in the absence of what one reviewer called "old unreliable data" (see comments 14 and 22). Only utilized were the new data above 0.5 in/sec, which included 28 observations of threshold damage. The second run examined all the low-frequency data minus the non-blasting shaker tests (fig. 1), primarily as a result of comment 6. Finally, the analysis in figure 3 represents a rerun of that in figure 2 except for two inadvertantly omitted points (see comment 31).

As expected, none of these new plots produced results very much different than those in RI 8507. The new Bureau data alone (fig. 2) still suggests safe values of vibration (below 40 Hz) between 0.3 and 0.8 in/sec. The 95 pct safe value from the points (rather than the regression line) is approximately 0.70 in/sec.

The other two plots (figs. 2 and 3) are close to undistinguishable from each other. They suggest that 0.50 in/sec would be an appropriate safe value (95 pct to 98 pct), virtually the same as figure 57 of the RI, with the maverick low-valued point ignored.

For the reasons stated in RI 8507, it is still felt that the 0.50 in/sec safe-level criteria be used for sensitive cases and that 0.75 in/sec be the basic recommendation.



APPARENT SLOPE OF LINE = 2.57 INCHES PER INCH

CORRELATION COEFFICIENT = .973

Figure 1. - Probability damage analysis for new Bureau of Mines data alone, threshold.

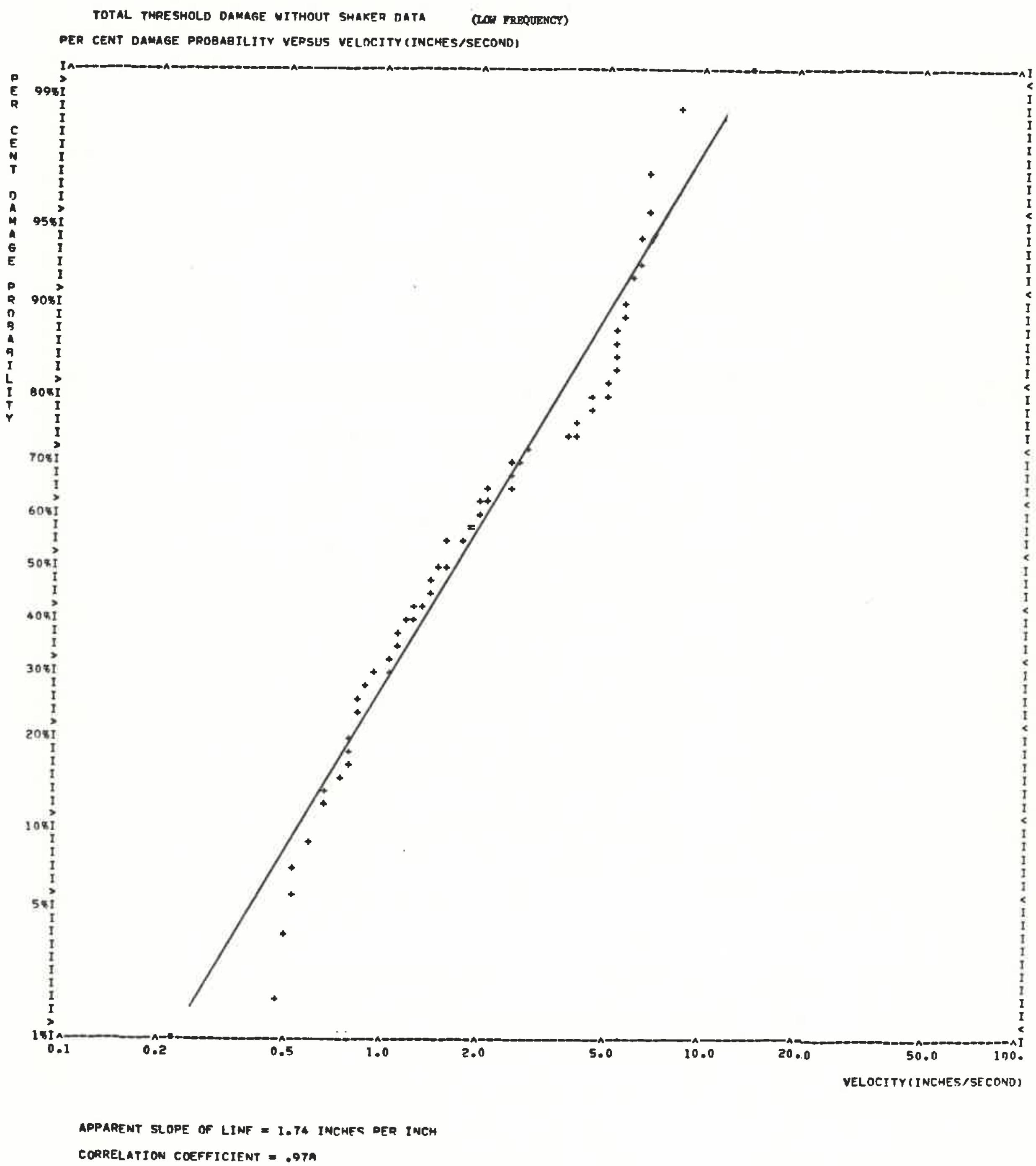


Figure 2. - Probability damage analysis for all low-frequency blasts (no shaker tests), threshold.

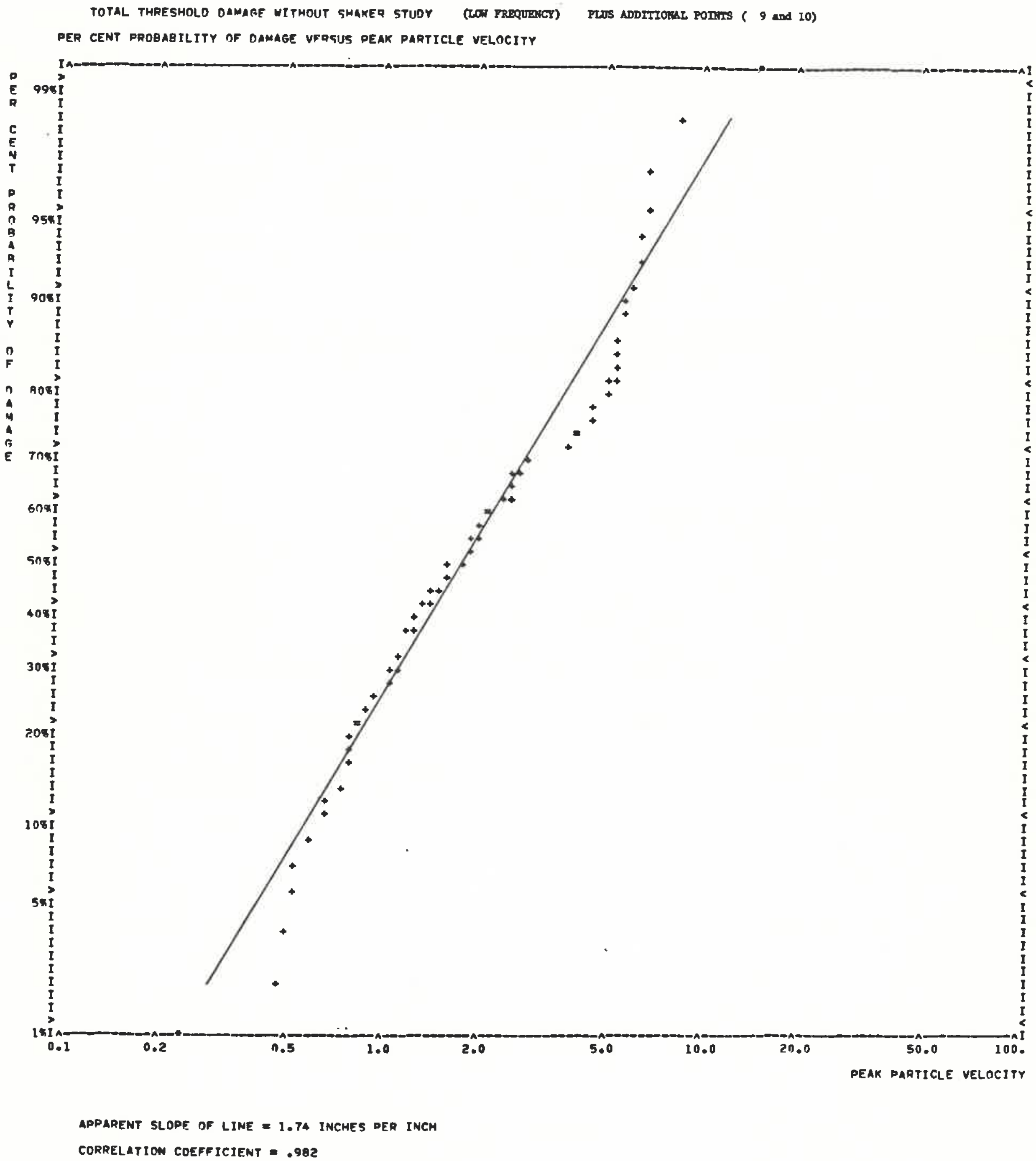


Figure 3. - Probability damage analysis for all low-frequency blasts (no shaker tests) plus two additional points, 9 and 10, threshold.

RAW DAMAGE DATA USED IN RI 8507

The following table contains the damage and nondamage values from the 10 studies. These represent the sum total of useful blast damage data that was found and used to produce the results in RI 8507, figures 48 to 59, as well as figures 1 to 3 of this OFR.

During preparation of this table and the additional plots, a few minor omissions and discrepancies were found in the RI. These consisted of shots that should have been included in table 1, some slight systematic errors in nine of the values in table 1, and other minor items (such as table 9 should show 28 threshold damage points and 76 nondamage points above 0.2 in/sec for the new Bureau data).

The new Bureau data are labeled "Siskind Group". Shown are both the values used in the RI 8507 analyses as well as 25 additional predominately nondamage points of mostly low level. Some other damage data were found during preparation of the printouts. They had not been used in the original analyses because they were obtained late and had such superficial damage as to be of questionable validity (shots 198, 199, 201, 202). Very light crack extensions were observed for shots 198 and 199, and no damage for 201 and 202.

It is appropriate to point out some characteristics of the Bureau data for anyone desiring to do their own analysis. The principle of superposition was used for the nondamage evaluation. That is, the 37 relatively high level blasts which did not produce damage are represented by 76 vibration time histories above 0.2 in/sec in RI 8507, figures 46 and 47. Each of these vibrations can be treated as a seperate event. However, superposition was not used for the analysis of the damage values. There was no practical way to identify which component of motion was responsible for the observed cracking. Consequently, the 30 damage values in the table and used for preparation of figure 1 of this report are all from different blasts.

There are multiple listings in the data table. For some shots (e.g., 104), there were two structures instrumented and studied simultaneously. In addition, many of the structures were subjected to a long series of blasts (e.g., No. 21).

None of the errors is significant enough to make a noticeable change in figures 48 through 59; however, they did affect the new Bureau-data-alone plot included as figure 1 of this OFR. The table of vibrations and the plots in this OFR correspond to the fully corrected values.

Because there were some other minor errors in RI 8507, mostly in transcription, an errata sheet has been prepared and is included in this report.

OPEN FILE REPORT

Supplimentary Information for Bureau of Mines Study on Response and Damage Produced by Ground Vibrations From Blasting, RI 8507

By D. E. Siskind

Raw Data

UNITED STATES DEPARTMENT OF THE INTERIOR
James Watt, Secretary

BUREAU OF MINES
Hermann Enzer, Acting Director

CONTENTS

United States Department of the Interior

BUREAU OF MINES

TWIN CITIES RESEARCH CENTER
5629 MINNEHAHA AVENUE SOUTH
MINNEAPOLIS, MINNESOTA 55417

March 4, 1981

Memorandum

To: Donald E. Ralston, Chief, Branch of Technology Transfer, Division of Minerals Health and Safety Technology

Through: Donald G. Rogich, Director, Division of Research Center Operations, Washington, D.C.
David R. Forshey, Director, Division of Minerals Environmental Technology, Washington, D.C.
John W. Corwine, Research Director, TCRC
Dennis V. D'Andrea, Research Supervisor, Blasting Technology and In Situ Mining, TCRC

From: David E. Siskind, Group Supervisor, Blasting Technology, TCRC

Subject: Approval Request for Open Filing of "Supplimentary Information for Bureau of Mines Sudy on Response and Damage Produced by Ground Vibrations from Blasting, RI 8507"

A presentation was made of the Bureau of Mines research reported in RI 8507 at the meeting of the National Crushed Stone Association in New Orleans, January 13, 1981. At that time, questions were raised about the availability of the raw data used for the analyses and also some additional plots. Dr. Lindsey Norman was in attendance and suggested that this material be made available on open file.

As a result, the subject draft OFR has been prepared. In addition to the two above items, the report contains the 55 most significant review comments made about RI 8507, replies to these comments, and an errata sheet.

I request that this report be placed on open file at the major Bureau of Mines Centers and libraries and also made available through NTIS.

Enclosed are four copies of the report.

David E. Siskind

DAVID E. SISKIND

Enclosures

cc: D. D'Andrea
R. Dick
C. Dowding

RAW DAMAGE DATA USED IN RI 8507

103 BUMINES NONDAMAGE DATA

Bull 442
Shaker system
Ref. 51

		Hz	in	in/sec	in/sec^2
BUREAU OF MINES	NONDAMAGE	F= 12.6511	D=.0855540	V= 6.80062	A= 540.576
BUREAU OF MINES	NONDAMAGE	F= 13.2863	D=.0899701	V= 7.51073	A= 626.998
BUREAU OF MINES	NONDAMAGE	F= 12.4056	D=.0750602	V= 5.85069	A= 456.042
BUREAU OF MINES	NONDAMAGE	F= 10.8154	D=.0501818	V= 3.41011	A= 231.735
BUREAU OF MINES	NONDAMAGE	F= 12.2846	D=.0638946	V= 4.93180	A= 380.668
BUREAU OF MINES	NONDAMAGE	F= 13.2863	D=.0560575	V= 4.67970	A= 390.662
BUREAU OF MINES	NONDAMAGE	F= 15.8489	D=.0765866	V= 7.62661	A= 759.470
BUREAU OF MINES	NONDAMAGE	F= 13.6826	D=.0501818	V= 4.31414	A= 370.888
BUREAU OF MINES	NONDAMAGE	F= 15.5414	D=.0560575	V= 5.47399	A= 534.532
BUREAU OF MINES	NONDAMAGE	F= 14.7983	D=.0501818	V= 4.66593	A= 433.840
BUREAU OF MINES	NONDAMAGE	F= 22.5523	D=.0560575	V= 7.94336	A= 1125.577
BUREAU OF MINES	NONDAMAGE	F= 14.6540	D=.0566246	V= 5.21364	A= 480.040
BUREAU OF MINES	NONDAMAGE	F= 20.8521	D=.0560575	V= 7.34452	A= 962.261
BUREAU OF MINES	NONDAMAGE	F= 16.1792	D=.0363627	V= 4.15347	A= 474.423
BUREAU OF MINES	NONDAMAGE	F= 17.1413	D=.0444721	V= 4.78973	A= 515.864
BUREAU OF MINES	NONDAMAGE	F= 21.4741	D=.0444721	V= 6.00043	A= 809.613
BUREAU OF MINES	NONDAMAGE	F= 27.1671	D=.0356379	V= 6.08324	A= 1038.385
BUREAU OF MINES	NONDAMAGE	F= 32.4070	D=.0309535	V= 6.30273	A= 1283.356
BUREAU OF MINES	NONDAMAGE	F= 13.2863	D=.0410313	V= 3.42530	A= 285.945
BUREAU OF MINES	NONDAMAGE	F= 15.2398	D=.0363627	V= 3.48189	A= 333.407
BUREAU OF MINES	NONDAMAGE	F= 17.3100	D=.0332133	V= 3.61234	A= 392.885
BUREAU OF MINES	NONDAMAGE	F= 27.1671	D=.0274316	V= 4.68246	A= 799.277
BUREAU OF MINES	NONDAMAGE	F= 28.2530	D=.0263491	V= 4.67746	A= 830.338
BUREAU OF MINES	NONDAMAGE	F= 31.1614	D=.0250557	V= 4.90573	A= 960.506
BUREAU OF MINES	NONDAMAGE	F= 33.3737	D=.0162528	V= 3.40810	A= 714.655
BUREAU OF MINES	NONDAMAGE	F= 23.6847	D=.0209035	V= 3.11076	A= 462.929
BUREAU OF MINES	NONDAMAGE	F= 19.6615	D=.0211150	V= 2.60848	A= 322.243
BUREAU OF MINES	NONDAMAGE	F= 13.8174	D=.0328806	V= 2.85460	A= 247.829
BUREAU OF MINES	NONDAMAGE	F= 14.7983	D=.0300328	V= 2.79246	A= 259.645
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BUREAU OF MINES	NONDAMAGE	F= 9.9025	D=.0335493	V= 2.08741	A= 129.877
BUREAU OF MINES	NONDAMAGE	F= 9.0666	D=.0332133	V= 1.89207	A= 107.786
BUREAU OF MINES	NONDAMAGE	F= 5.8913	D=.0250557	V= .92747	A= 34.331
BUREAU OF MINES	NONDAMAGE	F= 10.0000	D=.0453765	V= 2.85109	A= 179.139
BUREAU OF MINES	NONDAMAGE	F= 7.9045	D=.0462992	V= 2.29947	A= 114.204
BUREAU OF MINES	NONDAMAGE	F= 9.4291	D=.0506895	V= 3.00309	A= 177.917
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BUREAU OF MINES	NONDAMAGE	F= 8.7182	D=.0449220	V= 2.46074	A= 134.795
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BUREAU OF MINES	NONDAMAGE	F= 9.3371	D=.0758196	V= 4.44809	A= 260.955
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BUREAU OF MINES	NONDAMAGE	F= 8.8040	D=.0543900	V= 3.00870	A= 166.433
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BUREAU OF MINES	NONDAMAGE	F= 6.8241	D=.0908803	V= 3.89668	A= 167.078
BUREAU OF MINES	NONDAMAGE	F= 7.6007	D=.0872938	V= 4.16886	A= 199.090
BUREAU OF MINES	NONDAMAGE	F= 6.8241	D=.1015213	V= 4.35294	A= 186.641
BUREAU OF MINES	NONDAMAGE	F= 6.8241	D=.1134083	V= 4.86262	A= 208.495
BUREAU OF MINES	NONDAMAGE	F= 8.3831	D=.0872938	V= 4.59799	A= 242.188
BUREAU OF MINES	NONDAMAGE	F= 9.4291	D=.0864196	V= 5.11991	A= 303.328
BUREAU OF MINES	NONDAMAGE	F= 7.9823	D=.0936666	V= 4.69778	A= 235.614
BUREAU OF MINES	NONDAMAGE	F= 11.2477	D=.0765866	V= 5.41248	A= 382.508
BUREAU OF MINES	NONDAMAGE	F= 11.8125	D=.0864196	V= 6.41407	A= 476.053
BUREAU OF MINES	NONDAMAGE	F= 10.3997	D=.0855540	V= 5.59038	A= 365.293
BUREAU OF MINES	NONDAMAGE	F= 7.6755	D=.1005046	V= 4.84699	A= 233.754
BUREAU OF MINES	NONDAMAGE	F= 10.2983	D=.1005046	V= 6.50326	A= 420.801
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BUREAU OF MINES      NONDAMAGE          F=  9.8059 D=.1580910 V= 9.74035 A=   600.125
BUREAU OF MINES      NONDAMAGE          F=  7.3085 D=.1100348 V= 5.05287 A=   232.031
BUREAU OF MINES      NONDAMAGE          F=  7.9823 D=.2159863 V=10.83264 A=   543.303
BUREAU OF MINES      NONDAMAGE          F=  9.1559 D=.1801929 V=10.36618 A=   596.348
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BUREAU OF MINES      NONDAMAGE          F= 19.6615 D=.0169206 V= 2.09032 A=   258.231
BUREAU OF MINES      NONDAMAGE          F= 38.6575 D=.0153003 V= 3.71632 A=   902.666
BUREAU OF MINES      NONDAMAGE          F=  6.4344 D=.0151470 V=   .61237 A=    24.757
BUREAU OF MINES      NONDAMAGE          F=  6.8912 D=.0131561 V=   .56964 A=    24.665
BUREAU OF MINES      NONDAMAGE          F=  8.8907 D=.0121382 V=   .67806 A=    37.878
BUREAU OF MINES      NONDAMAGE          F= 13.9534 D=.0120166 V= 1.05352 A=    92.364
BUREAU OF MINES      NONDAMAGE          F= 26.2530 D=.0121382 V= 2.15476 A=   382.510
BUREAU OF MINES      NONDAMAGE          F= 33.3737 D=.0101266 V= 2.12348 A=   445.279
BUREAU OF MINES      NONDAMAGE          F=  8.4656 D=.0100252 V=   .53325 A=    28.364
BUREAU OF MINES      NONDAMAGE          F=  6.9591 D=.0080337 V=   .35128 A=    15.360
BUREAU OF MINES      NONDAMAGE          F= 10.2983 D=.0069778 V=   .45151 A=    29.215
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BUREAU OF MINES      NONDAMAGE          F=  6.7575 D=.0059999 V=   .25475 A=    10.816
BUREAU OF MINES      NONDAMAGE          F= 18.7215 D=.0060606 V=   .71291 A=    83.860
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BUREAU OF MINES      NONDAMAGE          F= 24.8739 D=.0060606 V=   .94719 A=   148.035
BUREAU OF MINES      NONDAMAGE          F=  4.0203 D=.0040518 V=   .10235 A=     2.585
BUREAU OF MINES      NONDAMAGE          F=  8.3831 D=.0029957 V=   .15779 A=     8.311
BUREAU OF MINES      NONDAMAGE          F= 24.6314 D=.0039711 V=   .61458 A=    95.115
BUREAU OF MINES      NONDAMAGE          F= 29.3823 D=.0040112 V=   .74053 A=   136.712
BUREAU OF MINES      NONDAMAGE          F= 34.7077 D=.0038919 V=   .84873 A=   185.086
BUREAU OF MINES      NONDAMAGE          F=  2.0051 D=.0019045 V=   .02399 A=      .302
BUREAU OF MINES      NONDAMAGE          F= 17.8264 D=.0024993 V=   .27994 A=    31.355
BUREAU OF MINES      NONDAMAGE          F= 17.6526 D=.0011986 V=   .13294 A=    14.745
   26          BUMINES THRESHOLD DAMAGE DATA (FORMERLY CALLED MINOR DAMAGE DATA)
BUREAU OF MINES      THRESHOLD          F= 10.8154 D=.1914111 V=13.00737 A=   883.918
BUREAU OF MINES      THRESHOLD          F=  7.9045 D=.2294329 V=11.39489 A=   565.932
BUREAU OF MINES      THRESHOLD          F= 10.9219 D=.3010846 V=20.66173 A=  1417.897
BUREAU OF MINES      THRESHOLD          F=  8.8907 D=.2294329 V=12.81656 A=   715.958
BUREAU OF MINES      THRESHOLD          F=  9.6157 D=.2294329 V=13.86170 A=   837.485
BUREAU OF MINES      THRESHOLD          F=  7.6755 D=.1992753 V= 9.61037 A=   463.475
BUREAU OF MINES      THRESHOLD          F=  9.6157 D=.1005046 V= 6.07221 A=   366.866
BUREAU OF MINES      THRESHOLD          F=  6.9782 D=.1111480 V= 6.27005 A=   353.704
BUREAU OF MINES      THRESHOLD          F= 11.9288 D=.1216675 V= 9.12058 A=   683.596
BUREAU OF MINES      THRESHOLD          F= 10.9219 D=.0908803 V= 6.23660 A=   427.982
BUREAU OF MINES      THRESHOLD          F= 19.6615 D=.0607584 V= 7.50590 A=   927.255
BUREAU OF MINES      THRESHOLD          F=  9.6157 D=.0946142 V= 5.71633 A=   345.365
BUREAU OF MINES      THRESHOLD          F=  6.8907 D=.0908803 V= 5.07675 A=   283.597
BUREAU OF MINES      THRESHOLD          F=  7.4532 D=.0805399 V= 3.77167 A=   176.627
BUREAU OF MINES      THRESHOLD          F=  7.3805 D=.0758196 V= 3.51599 A=   163.047
BUREAU OF MINES      THRESHOLD          F= 14.7983 D=.0713760 V= 6.63657 A=   617.072
BUREAU OF MINES      THRESHOLD          F= 12.7756 D=.0577762 V= 4.63778 A=   372.281
BUREAU OF MINES      THRESHOLD          F=  9.9025 D=.0386265 V= 2.40331 A=   149.532
BUREAU OF MINES      THRESHOLD          F= 16.6447 D=.0402135 V= 4.20560 A=   439.829
BUREAU OF MINES      THRESHOLD          F= 28.8121 D=.0410313 V= 7.42797 A=  1344.698
BUREAU OF MINES      THRESHOLD          F= 19.8551 D=.0300328 V= 3.74669 A=   467.412
BUREAU OF MINES      THRESHOLD          F=  6.4978 D=.0274316 V= 1.11995 A=    45.724
BUREAU OF MINES      THRESHOLD          F= 26.6399 D=.0081150 V= 1.35832 A=   227.360
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Bull 442
Shaker system
Ref. 51

BUREAU OF MINES	THRESHOLD	F= 32.0910	D=.0062464	V= 1.25948	A= 253.955
BUREAU OF MINES	THRESHOLD	F= 39.8107	D=.0040928	V= 1.02376	A= 256.082
BUREAU OF MINES	THRESHOLD	F= 40.2027	D=.0012108	V= .30585	A= 77.258
34	BUMINES MINOR DAMAGE DATA	(FORMERLY CALLED MAJOR DAMAGE DATA)			
BUREAU OF MINES	MINOR DAMAGE	F= 8.8040	D=.4549079	V=25.16421	A= 1392.013
BUREAU OF MINES	MINOR DAMAGE	F= 9.3371	D=.1992753	V=11.69083	A= 685.863
BUREAU OF MINES	MINOR DAMAGE	F= 11.6973	D=.2834386	V=20.83169	A= 1531.052
BUREAU OF MINES	MINOR DAMAGE	F= 9.9025	D=.2138231	V=13.30391	A= 827.759
BUREAU OF MINES	MINOR DAMAGE	F= 9.4291	D=.2095615	V=12.41543	A= 735.549
BUREAU OF MINES	MINOR DAMAGE	F= 8.7182	D=.2074626	V=11.36440	A= 622.520
BUREAU OF MINES	MINOR DAMAGE	F= 9.4291	D=.1894941	V=11.22654	A= 665.114
BUREAU OF MINES	MINOR DAMAGE	F= 8.3014	D=.2033278	V=10.60542	A= 553.171
BUREAU OF MINES	MINOR DAMAGE	F= 8.6332	D=.1894941	V=10.27892	A= 557.570
BUREAU OF MINES	MINOR DAMAGE	F= 9.3371	D=.1696322	V= 9.95177	A= 583.838
BUREAU OF MINES	MINOR DAMAGE	F= 8.3831	D=.1696322	V= 8.93496	A= 470.628
BUREAU OF MINES	MINOR DAMAGE	F= 8.8907	D=.1503312	V= 8.39779	A= 469.117
BUREAU OF MINES	MINOR DAMAGE	F= 8.3831	D=.0994980	V= 5.24082	A= 276.047
BUREAU OF MINES	MINOR DAMAGE	F= 8.8907	D=.1292634	V= 7.22090	A= 403.373
BUREAU OF MINES	MINOR DAMAGE	F= 8.3014	D=.1111480	V= 5.79739	A= 302.388
BUREAU OF MINES	MINOR DAMAGE	F= 8.9782	D=.0985014	V= 5.55663	A= 313.459
BUREAU OF MINES	MINOR DAMAGE	F= 10.0000	D=.0908803	V= 5.71018	A= 358.781
BUREAU OF MINES	MINOR DAMAGE	F= 7.9823	D=.0750602	V= 3.76459	A= 188.810
BUREAU OF MINES	MINOR DAMAGE	F= 19.6615	D=.1992753	V=24.61784	A= 3041.211
BUREAU OF MINES	MINOR DAMAGE	F= 17.4805	D=.1992753	V=21.88705	A= 2403.925
BUREAU OF MINES	MINOR DAMAGE	F= 11.6973	D=.1503312	V=11.04879	A= 812.045
BUREAU OF MINES	MINOR DAMAGE	F= 13.6826	D=.1503312	V=12.92402	A= 1111.082
BUREAU OF MINES	MINOR DAMAGE	F= 18.5389	D=.1415206	V=16.48479	A= 1920.204
BUREAU OF MINES	MINOR DAMAGE	F= 11.9288	D=.1100348	V= 8.24720	A= 618.135
BUREAU OF MINES	MINOR DAMAGE	F= 14.9440	D=.1005046	V= 9.43697	A= 886.093
BUREAU OF MINES	MINOR DAMAGE	F= 28.2530	D=.0462992	V= 8.21898	A= 1459.024
BUREAU OF MINES	MINOR DAMAGE	F= 23.6847	D=.0406203	V= 6.04492	A= 899.578
BUREAU OF MINES	MINOR DAMAGE	F= 19.8551	D=.0356379	V= 4.44594	A= 554.646
BUREAU OF MINES	MINOR DAMAGE	F= 23.9179	D=.0309535	V= 4.65171	A= 699.062
BUREAU OF MINES	MINOR DAMAGE	F= 21.6855	D=.0309535	V= 4.21754	A= 574.657
BUREAU OF MINES	MINOR DAMAGE	F= 29.6716	D=.0248048	V= 4.62441	A= 862.139
BUREAU OF MINES	MINOR DAMAGE	F= 34.7077	D=.0090652	V= 1.97689	A= 431.111
BUREAU OF MINES	MINOR DAMAGE	F= 8.3014	D=.0501818	V= 2.61744	A= 136.524
BUREAU OF MINES	MINOR DAMAGE	F= 8.8040	D=.0501818	V= 2.77591	A= 153.556

Bull 442
Shaker system
Ref. 51

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   57       LANGEFORS NONDAMAGE DATA                                                Ref. 25
LANGEFORS            NONDAMAGE         F= 61.3252 D=.0120359 V= 4.63764 A= 1786.966
LANGEFORS            NONDAMAGE         F= 53.3234 D=.0110082 V= 3.68820 A= 1235.696
LANGEFORS            NONDAMAGE         F= 52.8595 D=.0101586 V= 3.37394 A= 1120.572
LANGEFORS            NONDAMAGE         F= 58.1927 D=.0121437 V= 4.44017 A= 1623.483
LANGEFORS            NONDAMAGE         F= 47.5973 D=.0110082 V= 3.29214 A=  984.557
LANGEFORS            NONDAMAGE         F= 49.2904 D=.0079124 V= 2.45048 A=  758.914
LANGEFORS            NONDAMAGE         F= 79.0125 D=.0119289 V= 5.92210 A= 2940.030
LANGEFORS            NONDAMAGE         F= 56.6870 D=.0083476 V= 2.97321 A= 1058.981
LANGEFORS            NONDAMAGE         F= 64.0640 D=.0093745 V= 3.77348 A= 1518.924
LANGEFORS            NONDAMAGE         F= 66.9252 D=.0076349 V= 3.21050 A= 1350.027
LANGEFORS            NONDAMAGE         F= 82.5413 D=.0080549 V= 4.17745 A= 2166.519
LANGEFORS            NONDAMAGE         F=100.0375 D=.0083476 V= 5.24692 A= 3297.972
LANGEFORS            NONDAMAGE         F=108.2227 D=.0079833 V= 5.42851 A= 3691.296
LANGEFORS            NONDAMAGE         F= 98.3043 D=.0067985 V= 4.19919 A= 2593.689
LANGEFORS            NONDAMAGE         F=100.0375 D=.0063300 V= 3.97875 A= 2500.858
LANGEFORS            NONDAMAGE         F= 99.1671 D=.0058415 V= 3.63975 A= 2267.876
LANGEFORS            NONDAMAGE         F=128.8901 D=.0067381 V= 5.45679 A= 4419.125
LANGEFORS            NONDAMAGE         F=132.3137 D=.0061081 V= 5.07798 A= 4221.585
LANGEFORS            NONDAMAGE         F=131.1625 D=.0054877 V= 4.52251 A= 3727.086
LANGEFORS            NONDAMAGE         F=132.3137 D=.0045094 V= 3.74890 A= 3116.651
LANGEFORS            NONDAMAGE         F=161.7675 D=.0062181 V= 6.32017 A= 6423.918
LANGEFORS            NONDAMAGE         F=104.5052 D=.0052482 V= 3.44610 A= 2262.799
LANGEFORS            NONDAMAGE         F=110.1307 D=.0051096 V= 3.53570 A= 2446.603
LANGEFORS            NONDAMAGE         F= 86.9844 D=.0053427 V= 2.91999 A= 1595.891
LANGEFORS            NONDAMAGE         F=101.8012 D=.0048001 V= 3.07032 A= 1963.884
LANGEFORS            NONDAMAGE         F=110.1307 D=.0047152 V= 3.26278 A= 2257.754
LANGEFORS            NONDAMAGE         F=102.6947 D=.0043903 V= 2.83284 A= 1827.890
LANGEFORS            NONDAMAGE         F=201.2649 D=.0055865 V= 7.06460 A= 8933.788
LANGEFORS            NONDAMAGE         F=229.4531 D=.0030179 V= 4.35090 A= 6272.670
LANGEFORS            NONDAMAGE         F=217.7326 D=.0024144 V= 3.30303 A= 4518.725
LANGEFORS            NONDAMAGE         F=201.2649 D=.0028099 V= 3.55336 A= 4493.520
LANGEFORS            NONDAMAGE         F=270.8945 D=.0032996 V= 5.61618 A= 9559.197
LANGEFORS            NONDAMAGE         F=181.2288 D=.0034195 V= 3.89376 A= 4433.807
LANGEFORS            NONDAMAGE         F=181.2288 D=.0031839 V= 3.62549 A= 4128.322
LANGEFORS            NONDAMAGE         F=158.9649 D=.0032124 V= 3.20856 A= 3204.733
LANGEFORS            NONDAMAGE         F=190.9842 D=.0025245 V= 3.02937 A= 3635.214
LANGEFORS            NONDAMAGE         F=259.3133 D=.0019840 V= 3.23256 A= 5266.850
LANGEFORS            NONDAMAGE         F=225.4778 D=.0020017 V= 2.83585 A= 4017.596
LANGEFORS            NONDAMAGE         F=257.0572 D=.0022082 V= 3.56655 A= 5760.467
LANGEFORS            NONDAMAGE         F=280.5307 D=.0019840 V= 3.49705 A= 6163.994
LANGEFORS            NONDAMAGE         F=298.2263 D=.0017984 V= 3.36986 A= 6314.485
LANGEFORS            NONDAMAGE         F=246.0676 D=.0011929 V= 1.84433 A= 2851.495
LANGEFORS            NONDAMAGE         F=261.5893 D=.0011929 V= 1.96067 A= 3222.580
LANGEFORS            NONDAMAGE         F=298.2263 D=.0011929 V= 2.23527 A= 4188.472
LANGEFORS            NONDAMAGE         F=328.3157 D=.0009979 V= 2.05854 A= 4246.490
LANGEFORS            NONDAMAGE         F=397.9084 D=.0007912 V= 1.97810 A= 4945.523
LANGEFORS            NONDAMAGE         F=257.0572 D=.0028099 V= 4.53838 A= 7330.104
LANGEFORS            NONDAMAGE         F=259.3133 D=.0026163 V= 4.26277 A= 6945.394
LANGEFORS            NONDAMAGE         F=298.2263 D=.0028351 V= 5.31244 A= 9954.513
LANGEFORS            NONDAMAGE         F=295.6316 D=.0022082 V= 4.10175 A= 7619.033
LANGEFORS            NONDAMAGE         F=342.9786 D=.0026873 V= 5.79113 A=12479.866
LANGEFORS            NONDAMAGE         F=367.8134 D=.0028099 V= 6.49379 A=15007.408
LANGEFORS            NONDAMAGE         F=358.2963 D=.0015044 V= 3.38677 A= 7624.436
LANGEFORS            NONDAMAGE         F=394.4465 D=.0015044 V= 3.72848 A= 9240.581
LANGEFORS            NONDAMAGE         F=397.9084 D=.0011929 V= 2.98241 A= 7456.414
LANGEFORS            NONDAMAGE         F=419.3277 D=.0009979 V= 2.62918 A= 6927.138
LANGEFORS            NONDAMAGE         F= 59.2187 D=.0088068 V= 3.27685 A= 1219.258
   32       LANGEFORS MINOR DAMAGE DATA
LANGEFORS            MINOR DAMAGE      F=139.4361 D=.0066189 V= 5.79884 A= 5080.378
LANGEFORS            MINOR DAMAGE      F=143.1398 D=.0061081 V= 5.49347 A= 4940.680   Ref. 25
LANGEFORS            MINOR DAMAGE      F=127.7687 D=.0063868 V= 5.12729 A= 4116.158
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LANGEFORS                MINOR DAMAGE      F=141.8944 D=.0056872 V= 5.07042 A= 4520.524
LANGEFORS                MINOR DAMAGE      F=118.1052 D=.0064441 V= 4.78202 A= 3548.624
LANGEFORS                MINOR DAMAGE      F=119.1417 D=.0059467 V= 4.45164 A= 3332.448
LANGEFORS                MINOR DAMAGE      F=123.3798 D=.0053427 V= 4.14176 A= 3210.766
LANGEFORS                MINOR DAMAGE      F=134.6464 D=.0079124 V= 6.69396 A= 5663.142
LANGEFORS                MINOR DAMAGE      F=128.8901 D=.0077033 V= 6.23844 A= 5052.143
LANGEFORS                MINOR DAMAGE      F=123.3798 D=.0074998 V= 5.81398 A= 4507.104
LANGEFORS                MINOR DAMAGE      F=119.1417 D=.0068595 V= 5.13495 A= 3843.968
LANGEFORS                MINOR DAMAGE      F=152.1689 D=.0046733 V= 4.46817 A= 4272.039
LANGEFORS                MINOR DAMAGE      F=164.6196 D=.0046318 V= 4.79083 A= 4955.330
LANGEFORS                MINOR DAMAGE      F=163.1873 D=.0049746 V= 5.10064 A= 5229.867
LANGEFORS                MINOR DAMAGE      F=208.4242 D=.0046733 V= 6.12000 A= 8014.560
LANGEFORS                MINOR DAMAGE      F=166.0644 D=.0039094 V= 4.07912 A= 4256.209
LANGEFORS                MINOR DAMAGE      F=176.5395 D=.0038402 V= 4.25967 A= 4724.952
LANGEFORS                MINOR DAMAGE      F=197.7779 D=.0039444 V= 4.90161 A= 6091.107
LANGEFORS                MINOR DAMAGE      F=275.6705 D=.0038402 V= 6.65157 A=11521.106
LANGEFORS                MINOR DAMAGE      F=295.6316 D=.0030179 V= 5.60577 A=10412.770
LANGEFORS                MINOR DAMAGE      F=322.6276 D=.0027850 V= 5.64555 A=11444.267
LANGEFORS                MINOR DAMAGE      F=290.5098 D=.0025930 V= 4.73307 A= 8639.405
LANGEFORS                MINOR DAMAGE      F=328.3157 D=.0023929 V= 4.93624 A=10182.809
LANGEFORS                MINOR DAMAGE      F=426.7207 D=.0020017 V= 5.36689 A=14389.515
LANGEFORS                MINOR DAMAGE      F=203.0313 D=.0050192 V= 6.40291 A= 8168.085
LANGEFORS                MINOR DAMAGE      F=163.1873 D=.0057896 V= 5.93629 A= 6086.688
LANGEFORS                MINOR DAMAGE      F=208.4242 D=.0066783 V= 8.74569 A=11453.071
LANGEFORS                MINOR DAMAGE      F=217.7326 D=.0039094 V= 5.34827 A= 7316.726
LANGEFORS                MINOR DAMAGE      F= 74.9765 D=.0096289 V= 4.53609 A= 2136.912
LANGEFORS                MINOR DAMAGE      F= 86.2276 D=.0088068 V= 4.77138 A= 2585.059
LANGEFORS                MINOR DAMAGE      F=121.2423 D=.0087285 V= 6.64927 A= 5065.329
LANGEFORS                MINOR DAMAGE      F=125.5551 D=.0097152 V= 7.66418 A= 6046.168
   16      LANGEFORS MAJOR DAMAGE DATA                                                            Ref. 25
LANGEFORS                MAJOR DAMAGE      F= 54.7398 D=.0280992 V= 9.66445 A= 3323.993
LANGEFORS                MAJOR DAMAGE      F= 58.7034 D=.0178246 V= 6.57450 A= 2424.968
LANGEFORS                MAJOR DAMAGE      F= 71.7712 D=.0141333 V= 6.37344 A= 2874.112
LANGEFORS                MAJOR DAMAGE      F= 90.8692 D=.0149108 V= 8.51329 A= 4860.647
LANGEFORS                MAJOR DAMAGE      F=108.2227 D=.0092087 V= 6.26176 A= 4257.893
LANGEFORS                MAJOR DAMAGE      F=148.2315 D=.0086510 V= 8.05725 A= 7504.246
LANGEFORS                MAJOR DAMAGE      F=149.5325 D=.0079833 V= 7.50063 A= 7047.148
LANGEFORS                MAJOR DAMAGE      F=206.6109 D=.0059467 V= 7.71985 A=10021.719
LANGEFORS                MAJOR DAMAGE      F=149.5325 D=.0058939 V= 5.53756 A= 5202.759
LANGEFORS                MAJOR DAMAGE      F=237.6152 D=.0054877 V= 8.19303 A=12232.030
LANGEFORS                MAJOR DAMAGE      F=150.8449 D=.0054390 V= 5.15501 A= 4885.849
LANGEFORS                MAJOR DAMAGE      F=290.5098 D=.0054877 V=10.01685 A=18284.019
LANGEFORS                MAJOR DAMAGE      F=237.6152 D=.0039094 V= 5.83666 A= 8714.015
LANGEFORS                MAJOR DAMAGE      F=295.6316 D=.0035123 V= 6.52413 A=12118.617
LANGEFORS                MAJOR DAMAGE      F=192.6605 D=.0058415 V= 7.07126 A= 8559.916
LANGEFORS                MAJOR DAMAGE      F=394.4465 D=.0032124 V= 7.96155 A=19731.748
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   22     EDWARDS/NORTHWOOD NONDAMAGE DATA
EDWARDS/NORTHWOOD  NONDAMAGE        F=  8.0128 D=.0373965 V= 1.88276 A=    94.789        Ref. 16
EDWARDS/NORTHWOOD  NONDAMAGE        F=  3.1641 D=.0818949 V= 1.62812 A=    32.368
EDWARDS/NORTHWOOD  NONDAMAGE        F=  2.9985 D=.1948449 V= 3.67090 A=    69.160
EDWARDS/NORTHWOOD  NONDAMAGE        F=  2.4938 D=.0570345 V=  .89367 A=    14.003
EDWARDS/NORTHWOOD  NONDAMAGE        F=  2.4938 D=.0434808 V=  .68130 A=    10.675
EDWARDS/NORTHWOOD  NONDAMAGE        F=  3.4166 D=.1175916 V= 2.52435 A=    54.191
EDWARDS/NORTHWOOD  NONDAMAGE        F=  2.5130 D=.1249002 V= 1.97213 A=    31.139
EDWARDS/NORTHWOOD  NONDAMAGE        F=  2.5130 D=.1727094 V= 2.72702 A=    43.059
EDWARDS/NORTHWOOD  NONDAMAGE        F=  2.9756 D=.1441306 V= 2.69470 A=    50.381
EDWARDS/NORTHWOOD  NONDAMAGE        F=  2.5130 D=.0916974 V= 1.44787 A=    22.861
EDWARDS/NORTHWOOD  NONDAMAGE        F=  7.0864 D=.0406292 V= 1.80902 A=    80.547
EDWARDS/NORTHWOOD  NONDAMAGE        F=  7.6520 D=.1066162 V= 5.12599 A=   246.452
EDWARDS/NORTHWOOD  NONDAMAGE        F=  3.0920 D=.0629058 V= 1.22211 A=    23.743
EDWARDS/NORTHWOOD  NONDAMAGE        F= 11.2338 D=.0663138 V= 4.68070 A=   330.382
EDWARDS/NORTHWOOD  NONDAMAGE        F=  5.0935 D=.0391265 V= 1.25218 A=    40.074
EDWARDS/NORTHWOOD  NONDAMAGE        F=  2.5130 D=.0673210 V= 1.06297 A=    16.784
EDWARDS/NORTHWOOD  NONDAMAGE        F= 25.7457 D=.0218991 V= 3.54251 A=   573.054
EDWARDS/NORTHWOOD  NONDAMAGE        F= 11.1478 D=.0197060 V= 1.38028 A=    96.680
EDWARDS/NORTHWOOD  NONDAMAGE        F= 11.1478 D=.0154829 V= 1.08448 A=    75.961
EDWARDS/NORTHWOOD  NONDAMAGE        F= 10.0887 D=.0241534 V= 1.53106 A=    97.053
EDWARDS/NORTHWOOD  NONDAMAGE        F= 25.5488 D=.0583388 V= 9.36500 A=  1503.344
EDWARDS/NORTHWOOD  NONDAMAGE        F= 16.4921 D=.0107828 V= 1.11735 A=   115.783
    6     EDWARDS/NORTHWOOD THRESHOLD DAMGE DATA
EDWARDS/NORTHWOOD  THRESHOLD        F=  9.9349 D=.0699064 V= 4.36375 A=   272.398        Ref. 16
EDWARDS/NORTHWOOD  THRESHOLD        F= 24.5864 D=.0247058 V= 3.81657 A=   589.588
EDWARDS/NORTHWOOD  THRESHOLD        F=  7.7704 D=.1287230 V= 6.28463 A=   306.833
EDWARDS/NORTHWOOD  THRESHOLD        F= 16.7473 D=.0368370 V= 3.87622 A=   407.881
EDWARDS/NORTHWOOD  THRESHOLD        F= 24.9669 D=.0794628 V=12.46546 A=  1955.478
EDWARDS/NORTHWOOD  THRESHOLD        F=  9.4150 D=.0889741 V= 5.26337 A=   311.361
    8     EDWARDS/NORTHWOOD MINOR DAMAGE DATA                                             Ref.16
EDWARDS/NORTHWOOD  MINOR DAMAGE     F= 24.7760 D=.0501754 V= 7.81091 A=  1215.942
EDWARDS/NORTHWOOD  MINOR DAMAGE     F= 24.7760 D=.1409082 V=21.93549 A=  3414.746
EDWARDS/NORTHWOOD  MINOR DAMAGE     F=  2.5130 D=.1978043 V= 3.12326 A=    49.315
EDWARDS/NORTHWOOD  MINOR DAMAGE     F=  2.5324 D=.2479907 V= 3.94591 A=    62.786
EDWARDS/NORTHWOOD  MINOR DAMAGE     F=  3.5504 D=.2498669 V= 5.57399 A=   124.343
EDWARDS/NORTHWOOD  MINOR DAMAGE     F= 11.0626 D=.0788661 V= 5.48185 A=   381.035
EDWARDS/NORTHWOOD  MINOR DAMAGE     F=  2.9985 D=.3481247 V= 6.55872 A=   123.567
EDWARDS/NORTHWOOD  MINOR DAMAGE     F= 17.1376 D=.0505550 V= 5.44370 A=   586.170
    5     EDWARDS/NORTHWOOD MAJOR DAMAGE DATA
EDWARDS/NORTHWOOD  MAJOR DAMAGE     F=  2.5324 D=.3782173 V= 6.01802 A=    95.756        Ref. 16
EDWARDS/NORTHWOOD  MAJOR DAMAGE     F= 11.1478 D=.0910088 V= 6.37459 A=   446.500
EDWARDS/NORTHWOOD  MAJOR DAMAGE     F= 10.8939 D=.1793422 V=12.27569 A=   840.251
EDWARDS/NORTHWOOD  MAJOR DAMAGE     F= 10.0887 D=.1316668 V= 8.34625 A=   529.062
EDWARDS/NORTHWOOD  MAJOR DAMAGE     F=  9.4150 D=.0753790 V= 4.45913 A=   263.785
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51 NORTHWOOD/CRAWFORD NONDAMAGE DATA					
NORTHWOOD/CRAWFORD NONDAMAGE	F= 47.0	D=.0011175	V= .33	A= 97.452	Ref. 38
NORTHWOOD/CRAWFORD NONDAMAGE	F= 29.0	D=.0024148	V= .44	A= 80.173	
NORTHWOOD/CRAWFORD NONDAMAGE	F= 24.0	D=.0062999	V= .95	A= 143.257	
NORTHWOOD/CRAWFORD NONDAMAGE	F= 20.0	D=.0018303	V= .23	A= 28.903	
NORTHWOOD/CRAWFORD NONDAMAGE	F= 18.0	D=.0075157	V= .85	A= 96.133	
NORTHWOOD/CRAWFORD NONDAMAGE	F= 25.0	D=.0101859	V= 1.60	A= 251.327	
NORTHWOOD/CRAWFORD NONDAMAGE	F= 54.0	D=.0011789	V= .40	A= 135.717	
NORTHWOOD/CRAWFORD NONDAMAGE	F= 10.0	D=.0381972	V= 2.40	A= 150.796	
NORTHWOOD/CRAWFORD NONDAMAGE	F= 65.0	D=.0040401	V= 1.65	A= 673.872	
NORTHWOOD/CRAWFORD NONDAMAGE	F= 8.0	D=.0457570	V= 2.30	A= 115.611	
NORTHWOOD/CRAWFORD NONDAMAGE	F= 22.0	D=.0068003	V= .94	A= 129.936	
NORTHWOOD/CRAWFORD NONDAMAGE	F= 29.0	D=.0060369	V= 1.10	A= 200.434	
NORTHWOOD/CRAWFORD NONDAMAGE	F= 16.0	D=.0368046	V= 3.70	A= 371.965	
NORTHWOOD/CRAWFORD NONDAMAGE	F= 22.0	D=.0245967	V= 3.40	A= 469.982	
NORTHWOOD/CRAWFORD NONDAMAGE	F= 29.0	D=.0016464	V= .30	A= 54.664	
NORTHWOOD/CRAWFORD NONDAMAGE	F= 13.0	D=.0061213	V= .50	A= 40.841	
NORTHWOOD/CRAWFORD NONDAMAGE	F= 37.0	D=.0098934	V= 2.30	A= 534.699	
NORTHWOOD/CRAWFORD NONDAMAGE	F= 54.0	D=.0053052	V= 1.80	A= 610.726	
NORTHWOOD/CRAWFORD NONDAMAGE	F=120.0	D=.0021221	V= 1.60	A= 1206.372	
NORTHWOOD/CRAWFORD NONDAMAGE	F= 36.0	D=.0083998	V= 1.90	A= 429.770	
NORTHWOOD/CRAWFORD NONDAMAGE	F= 38.0	D=.0050259	V= 1.20	A= 286.513	
NORTHWOOD/CRAWFORD NONDAMAGE	F= 36.0	D=.0045978	V= 1.04	A= 235.242	
NORTHWOOD/CRAWFORD NONDAMAGE	F= 35.0	D=.0204628	V= 4.50	A= 989.602	
NORTHWOOD/CRAWFORD NONDAMAGE	F= 44.0	D=.0047023	V= 1.30	A= 359.398	
NORTHWOOD/CRAWFORD NONDAMAGE	F= 25.0	D=.0063662	V= 1.00	A= 157.080	
NORTHWOOD/CRAWFORD NONDAMAGE	F= 26.0	D=.0134670	V= 2.20	A= 359.398	
NORTHWOOD/CRAWFORD NONDAMAGE	F= 45.0	D=.0007427	V= .21	A= 59.376	
NORTHWOOD/CRAWFORD NONDAMAGE	F= 18.0	D=.0035368	V= .40	A= 45.239	
NORTHWOOD/CRAWFORD NONDAMAGE	F= 24.0	D=.0026526	V= .40	A= 60.319	
NORTHWOOD/CRAWFORD NONDAMAGE	F= 70.0	D=.0003410	V= .15	A= 65.973	
NORTHWOOD/CRAWFORD NONDAMAGE	F= 40.0	D=.0015120	V= .38	A= 95.504	
NORTHWOOD/CRAWFORD NONDAMAGE	F= 15.0	D=.0044563	V= .42	A= 39.584	
NORTHWOOD/CRAWFORD NONDAMAGE	F= 70.0	D=.0006594	V= .29	A= 127.549	
NORTHWOOD/CRAWFORD NONDAMAGE	F= 62.0	D=.0043639	V= 1.70	A= 662.248	
NORTHWOOD/CRAWFORD NONDAMAGE	F= 64.0	D=.0018402	V= .74	A= 297.572	
NORTHWOOD/CRAWFORD NONDAMAGE	F= 25.0	D=.0042017	V= .66	A= 103.673	
NORTHWOOD/CRAWFORD NONDAMAGE	F= 30.0	D=.0051991	V= .98	A= 184.726	
NORTHWOOD/CRAWFORD NONDAMAGE	F= 20.0	D=.0270563	V= 3.40	A= 427.257	
NORTHWOOD/CRAWFORD NONDAMAGE	F= 26.0	D=.0177519	V= 2.90	A= 473.752	
NORTHWOOD/CRAWFORD NONDAMAGE	F= 32.0	D=.0014921	V= .30	A= 60.319	
NORTHWOOD/CRAWFORD NONDAMAGE	F= 39.0	D=.0013467	V= .33	A= 80.865	
NORTHWOOD/CRAWFORD NONDAMAGE	F= 44.0	D=.0050640	V= 1.40	A= 387.044	
NORTHWOOD/CRAWFORD NONDAMAGE	F= 28.0	D=.0068209	V= 1.20	A= 211.115	
NORTHWOOD/CRAWFORD NONDAMAGE	F=118.0	D=.0011195	V= .83	A= 615.375	
NORTHWOOD/CRAWFORD NONDAMAGE	F= 71.0	D=.0026899	V= 1.20	A= 535.327	
NORTHWOOD/CRAWFORD NONDAMAGE	F= 53.0	D=.0018018	V= .60	A= 199.805	
NORTHWOOD/CRAWFORD NONDAMAGE	F= 56.0	D=.0015631	V= .55	A= 193.522	
NORTHWOOD/CRAWFORD NONDAMAGE	F= 35.0	D=.0113682	V= 2.50	A= 549.779	
NORTHWOOD/CRAWFORD NONDAMAGE	F= 39.0	D=.0046930	V= 1.15	A= 281.801	
NORTHWOOD/CRAWFORD NONDAMAGE	F= 30.0	D=.0047746	V= .90	A= 169.646	
NORTHWOOD/CRAWFORD NONDAMAGE	F= 23.0	D=.0131476	V= 1.90	A= 274.575	
10 NORTHWOOD/CRAWFORD THRESHOLD DAMAGE DATA					Ref. 38
NORTHWOOD/CRAWFORD THRESHOLD	F= 12.0	D=.0888615	V= 6.70	A= 505.168	
NORTHWOOD/CRAWFORD THRESHOLD	F= 15.0	D=.0647230	V= 6.10	A= 574.911	
NORTHWOOD/CRAWFORD THRESHOLD	F= 9.0	D=.1467762	V= 8.30	A= 469.354	
NORTHWOOD/CRAWFORD THRESHOLD	F= 16.0	D=.0537148	V= 5.40	A= 542.867	
NORTHWOOD/CRAWFORD THRESHOLD	F= 16.0	D=.0497359	V= 5.00	A= 502.655	
NORTHWOOD/CRAWFORD THRESHOLD	F= 57.0	D=.0136817	V= 4.90	A= 1754.894	
NORTHWOOD/CRAWFORD THRESHOLD	F= 26.0	D=.0275460	V= 4.50	A= 735.133	
NORTHWOOD/CRAWFORD THRESHOLD	F= 20.0	D=.0541127	V= 6.80	A= 854.513	
NORTHWOOD/CRAWFORD THRESHOLD	F= 17.0	D=.0486827	V= 5.20	A= 555.434	

NORTHWOOD/CRAWFORD THRESHOLD	F= 22.0	D=.0405122	V= 5.60	A= 774.088
4 NORTHWOOD/CRAWFORD MINOR DAMAGE DATA				
NORTHWOOD/CRAWFORD MINOR DAMAGE	F= 10.0	D=.2196338	V=13.80	A= 667.080
NORTHWOOD/CRAWFORD MINOR DAMAGE	F= 12.0	D=.0503991	V= 3.80	A= 286.513
NORTHWOOD/CRAWFORD MINOR DAMAGE	F= 20.0	D=.0716197	V= 9.00	A= 1130.973
NORTHWOOD/CRAWFORD MINOR DAMAGE	F= 37.0	D=.0292501	V= 6.80	A= 1580.849
5 NORTHWOOD/CRAWFORD MAJOR DAMAGE DATA				
NORTHWOOD/CRAWFORD MAJOR DAMAGE	F= 17.0	D=.3052030	V=32.60	A= 3482.141
NORTHWOOD/CRAWFORD MAJOR DAMAGE	F= 8.0	D=.7559860	V=38.00	A= 1910.088
NORTHWOOD/CRAWFORD MAJOR DAMAGE	F= 18.0	D=.1078717	V=12.20	A= 1379.787
NORTHWOOD/CRAWFORD MAJOR DAMAGE	F= 16.0	D=.0676409	V= 6.80	A= 683.611
NORTHWOOD/CRAWFORD MAJOR DAMAGE	F= 18.0	D=.1149452	V=13.00	A= 1470.265

Ref. 38

Ref. 38

11 BOM B-442 NONDAMAGE QUARRY BLAST DATA			
BOM B-442 QUARRY	NONDAMAGE	F= 3.0	V= 0.942
BOM B-442 QUARRY	NONDAMAGE	F= 12.0	V= 0.45
BOM B-442 QUARRY	NONDAMAGE	F= 8.0	V= 0.45
BOM B-442 QUARRY	NONDAMAGE	F= 16.0	V= 0.32
BOM B-442 QUARRY	NONDAMAGE	F= 5.0	V= 0.47
BOM B-442 QUARRY	NONDAMAGE	F= 5.0	V= 0.345
BOM B-442 QUARRY	NONDAMAGE	F= 11.0	V= 0.829
BOM B-442 QUARRY	NONDAMAGE	F= 8.0	V= 0.502
BOM B-442 QUARRY	NONDAMAGE	F= 14.0	V= 0.44
BOM B-442 QUARRY	NONDAMAGE	F= 8.0	V= 0.502
BOM B-442 QUARRY	NONDAMAGE	F= 8.0	V= 0.402

Ref. 51

27 WOODWARD/CLYDE NONDAMAGE DATA (MAXIMUM OF V,R,T COMPONENTS)						
WOODWARD/CLYDE	4V NONDAMAGE	160.	F= 85.0	D=.0014418	V= .77	A= 411.234
WOODWARD/CLYDE	6R NONDAMAGE	75.	F= 66.6	D=.0008364	V= .35	A= 146.461
WOODWARD/CLYDE	7R NONDAMAGE	160.	F= 33.3	D=.0011471	V= .24	A= 50.215
WOODWARD/CLYDE	8R NONDAMAGE	120.	F= 33.3	D=.0012904	V= .27	A= 56.492
WOODWARD/CLYDE	9V NONDAMAGE	55.	F= 66.6	D=.0001912	V= .08	A= 33.477
WOODWARD/CLYDE	10V NONDAMAGE	30.	F=100.0	D=.0003501	V= .22	A= 138.230
WOODWARD/CLYDE	11V NONDAMAGE	185.	F= 66.6	D=.0009559	V= .40	A= 167.384
WOODWARD/CLYDE	12R NONDAMAGE	180.	F= 50.0	D=.0007958	V= .25	A= 78.540
WOODWARD/CLYDE	13T NONDAMAGE	48.	F= 43.0	D=.0040344	V= 1.09	A= 294.493
WOODWARD/CLYDE	14T NONDAMAGE	68.	F= 43.0	D=.0014805	V= .40	A= 108.071
WOODWARD/CLYDE	15T NONDAMAGE	75.	F= 40.0	D=.0012732	V= .32	A= 80.425
WOODWARD/CLYDE	16R NONDAMAGE	40.	F= 36.0	D=.0125556	V= 2.84	A= 642.393
WOODWARD/CLYDE	18T NONDAMAGE	140.	F=126.0	D=.0008716	V= .69	A= 546.260
WOODWARD/CLYDE	19V NONDAMAGE	115.	F=100.0	D=.0014801	V= .93	A= 584.336
WOODWARD/CLYDE	20R NONDAMAGE	65.	F= 47.0	D=.0017947	V= .53	A= 156.514
WOODWARD/CLYDE	21R NONDAMAGE	30.	F= 64.0	D=.0027106	V= 1.09	A= 438.315
WOODWARD/CLYDE	22R NONDAMAGE	100.	F= 51.0	D=.0048683	V= 1.56	A= 499.890
WOODWARD/CLYDE	23R NONDAMAGE	31.	F= 15.0	D=.0395765	V= 3.73	A= 351.544
WOODWARD/CLYDE	24V NONDAMAGE	70.	F= 57.0	D=.0049143	V= 1.76	A= 630.329
WOODWARD/CLYDE	25R NONDAMAGE	155.	F= 28.0	D=.0054567	V= .96	A= 168.892
WOODWARD/CLYDE	26R NONDAMAGE	150.	F= 28.0	D=.0091514	V= 1.61	A= 283.246
WOODWARD/CLYDE	27T NONDAMAGE	150.	F= 39.0	D=.0048971	V= 1.20	A= 294.053
WOODWARD/CLYDE	28V NONDAMAGE	93.	F= 43.0	D=.0046636	V= 1.26	A= 340.423
WOODWARD/CLYDE	29V NONDAMAGE	80.	F= 36.0	D=.0079577	V= 1.80	A= 407.150
WOODWARD/CLYDE	30T NONDAMAGE	100.	F= 21.0	D=.0021221	V= .28	A= 36.945
WOODWARD/CLYDE	31T NONDAMAGE	160.	F= 64.0	D=.0030339	V= 1.22	A= 490.591
WOODWARD/CLYDE	32R NONDAMAGE	75.	F= 51.0	D=.0056796	V= 1.82	A= 583.205
2 WOODWARD/CLYDE MINOR DAMAGE DATA (MAXIMUM OF V,R,T COMPONENTS)						
WOODWARD/CLYDE	5V MINOR	55.	F= 50.0	D=.0070983	V= 2.23	A= 700.575
WOODWARD/CLYDE	17T MINOR	5.	F= 11.0	D=.1717427	V=11.87	A= 820.396 ← Deleted from analysis

Ref. 21

Ref. 21

Shots as listed at the end of table 1 of RI 8507. Note, shot W5 produced damage in structure 61.

7	DVORAK NONDAMAGE DATA					
DVORAK	NONDAMAGE	F= 3.0	D=.0510	V= .96133 A=	18.121	Ref. 15
DVORAK	NONDAMAGE	F= 5.5	D=.0180	V= .62204 A=	21.496	
DVORAK	NONDAMAGE	F= 5.5	D=.0230	V= .79482 A=	27.467	
DVORAK	NONDAMAGE	F= 6.0	D=.0180	V= .67858 A=	25.582	
DVORAK	NONDAMAGE	F= 11.0	D=.0130	V= .89850 A=	62.100	
DVORAK	NONDAMAGE	F= 11.5	D=.0150	V= 1.08385 A=	78.315	
DVORAK	NONDAMAGE	F= 12.0	D=.0140	V= 1.05558 A=	79.588	
25	DVORAK THRESHOLD DAMAGE DATA					
DVORAK	THRESHOLD	F= 2.8	D=.0510	V= .89724 A=	15.785	Ref. 15
DVORAK	THRESHOLD	F= 3.0	D=.0370	V= .69743 A=	13.146	
DVORAK	THRESHOLD	F= 3.0	D=.0550	V= 1.03673 A=	19.542	
DVORAK	THRESHOLD	F= 3.5	D=.0260	V= .57177 A=	12.574	
DVORAK	THRESHOLD	F= 3.5	D=.0290	V= .63774 A=	14.025	
DVORAK	THRESHOLD	F= 3.5	D=.0390	V= .85765 A=	18.861	
DVORAK	THRESHOLD	F= 3.5	D=.0450	V= .98960 A=	21.762	
DVORAK	THRESHOLD	F= 3.8	D=.0350	V= .83566 A=	19.952	
DVORAK	THRESHOLD	F= 4.0	D=.0450	V= 1.13097 A=	28.424	
DVORAK	THRESHOLD	F= 4.5	D=.0180	V= .50894 A=	14.390	
DVORAK	THRESHOLD	F= 4.5	D=.0450	V= 1.27235 A=	35.975	
DVORAK	THRESHOLD	F= 4.5	D=.0510	V= 1.44199 A=	40.771	
DVORAK	THRESHOLD	F= 4.5	D=.0630	V= 1.78128 A=	50.365	
DVORAK	THRESHOLD	F= 4.5	D=.0870	V= 2.45987 A=	69.551	
DVORAK	THRESHOLD	F= 5.0	D=.0220	V= .69115 A=	21.713	
DVORAK	THRESHOLD	F= 5.0	D=.0290	V= .91106 A=	28.622	
DVORAK	THRESHOLD	F= 5.0	D=.0510	V= 1.60221 A=	50.335	
DVORAK	THRESHOLD	F= 5.5	D=.0260	V= .89850 A=	31.050	
DVORAK	THRESHOLD	F= 7.0	D=.0120	V= .52779 A=	23.213	
DVORAK	THRESHOLD	F= 7.0	D=.0350	V= 1.53938 A=	67.705	
DVORAK	THRESHOLD	F= 7.4	D=.0430	V= 1.99931 A=	92.959	
DVORAK	THRESHOLD	F= 8.0	D=.0510	V= 2.56354 A=	128.858	
DVORAK	THRESHOLD	F= 8.5	D=.0300	V= 1.60221 A=	85.569	
DVORAK	THRESHOLD	F= 7.3	D=.0290	V= 1.33015 A=	61.010	
DVORAK	THRESHOLD	F= 12.0	D=.0075	V= .56549 A=	42.637	
15	DVORAK MINOR DAMAGE DATA					
DVORAK	MINOR DAMAGE	F= 2.3	D=.0900	V= 1.27235 A=	17.987	Ref. 15
DVORAK	MINOR DAMAGE	F= 2.5	D=.0900	V= 1.41372 A=	22.207	
DVORAK	MINOR DAMAGE	F= 2.5	D=.0810	V= 1.27235 A=	19.986	
DVORAK	MINOR DAMAGE	F= 4.5	D=.0530	V= 1.49854 A=	42.370	
DVORAK	MINOR DAMAGE	F= 4.5	D=.0690	V= 1.95093 A=	55.161	
DVORAK	MINOR DAMAGE	F= 5.0	D=.0610	V= 1.91637 A=	60.205	
DVORAK	MINOR DAMAGE	F= 5.0	D=.0830	V= 2.60752 A=	81.918	
DVORAK	MINOR DAMAGE	F= 6.0	D=.0650	V= 2.45044 A=	92.379	
DVORAK	MINOR DAMAGE	F= 6.0	D=.0850	V= 3.20442 A=	120.804	
DVORAK	MINOR DAMAGE	F= 6.5	D=.0350	V= 1.42942 A=	58.379	
DVORAK	MINOR DAMAGE	F= 7.0	D=.0320	V= 1.40743 A=	61.902	
DVORAK	MINOR DAMAGE	F= 8.0	D=.0380	V= 1.91009 A=	96.012	
DVORAK	MINOR DAMAGE	F= 8.5	D=.0260	V= 1.38858 A=	74.160	
DVORAK	MINOR DAMAGE	F= 8.5	D=.1020	V= 5.44752 A=	290.936	
DVORAK	MINOR DAMAGE	F= 15.0	D=.0380	V= 3.58142 A=	337.540	
11	DVORAK MAJOR DAMAGE DATA					
DVORAK	MAJOR DAMAGE	F= 1.5	D=.2600	V= 2.45044 A=	23.095	Ref. 15
DVORAK	MAJOR DAMAGE	F= 2.2	D=.2700	V= 3.73221 A=	51.590	
DVORAK	MAJOR DAMAGE	F= 2.3	D=.2000	V= 2.89027 A=	41.768	
DVORAK	MAJOR DAMAGE	F= 2.5	D=.2600	V= 4.08407 A=	64.152	
DVORAK	MAJOR DAMAGE	F= 2.5	D=.1500	V= 2.35619 A=	37.011	
DVORAK	MAJOR DAMAGE	F= 2.5	D=.1300	V= 2.04204 A=	32.076	
DVORAK	MAJOR DAMAGE	F= 3.0	D=.1800	V= 3.39292 A=	63.955	
DVORAK	MAJOR DAMAGE	F= 3.8	D=.2400	V= 5.73026 A=	136.816	
DVORAK	MAJOR DAMAGE	F= 4.5	D=.1900	V= 5.37212 A=	151.893	
DVORAK	MAJOR DAMAGE	F= 4.5	D=.2600	V= 7.35133 A=	207.854	
DVORAK	MAJOR DAMAGE	F= 11.0	D=.1300	V= 8.98495 A=	620.996	

9 WISS II-77 NONDAMAGE DATA — Ref. 57

WISS II-77	NONDAMAGE	F= 11.0	V= 0.115	
WISS II-77	NONDAMAGE	F= 8.0	V= 0.525	
WISS II-77	NONDAMAGE	F= 55.0	V= 1.12	
WISS II-77	NONDAMAGE	F= 45.0	V= 2.12	
WISS II-77	NONDAMAGE	F= 39.0	V= 3.79	
WISS II-77	NONDAMAGE	F= 30.0	V= 4.57	
WISS II-77	NONDAMAGE	F= 30.0	V= 6.86	
WISS II-77	NONDAMAGE	F= 6.2	V= 5.36	
WISS II-77	NONDAMAGE	F= 44.0	V= 3.68	

1 WISS II-77 MINOR DAMAGE DATA — Ref. 57

WISS II-77	MINOR DAMAGE	F= 22.0	V=11.6

1 MORRIS II-102 NONDAMAGE DATA — Ref. 31

MORRIS II-102	NONDAMAGE	F= 16.0	V= 4.12

2 MORRIS II-102 THRESHOLD DAMAGE DATA — Ref. 31

MORRIS II-102	THRESHOLD	F= 3.7	V= 2.04
MORRIS II-102	THRESHOLD	F= 5.7	V= 2.65

30 SISKIND GROUP THRESHOLD DATA POINTS

SISKIND GROUP	4	THRESHOLD	F=17.40	D=.0174705	V= 1.91	A=208.81	STRUCTURE #	27	NEW B.M. DATA
SISKIND GROUP	7 ..	THRESHOLD	F=24.20	D=.0349220	V= 5.31	A=807.40		27	
SISKIND GROUP	9 *	THRESHOLD	F=20.00	D=.0186211	V= 2.34	A=294.05		27	
SISKIND GROUP	10 *	THRESHOLD	F=19.90	D=.0098065	V= 1.22	A=151.77		27	
SISKIND GROUP	11	THRESHOLD	F=21.00	D=.0054567	V= .72	A=895.00		27	
SISKIND GROUP	44	THRESHOLD	F=15.50	D=.0092840	V= .91	A=89.190		20	
SISKIND GROUP	45	THRESHOLD	F=14.30	D=.0125766	V= 1.13	A=101.53		20	
SISKIND GROUP	48	THRESHOLD	F=14.30	D=.0087925	V= .79	A=70.980		20	
SISKIND GROUP	60	THRESHOLD	F=31.00	D=.0059321	V= .88	A=113.34		19	
SISKIND GROUP	66	THRESHOLD	F=30.00	D=.0081169	V= 1.53	A=288.39		19	
SISKIND GROUP	78	THRESHOLD	F=25.00	D=.0100586	V= 1.58	A=248.18		19	
SISKIND GROUP	80	THRESHOLD	F=22.00	D=.0083195	V= 1.14	A=158.96		19	
SISKIND GROUP	94	THRESHOLD	F=18.00	D=.0124671	V= 1.41	A=159.46		19	
SISKIND GROUP	95	THRESHOLD	F=13.10	D=.0252704	V= 2.08	A=171.20		19	
SISKIND GROUP	96	THRESHOLD	F=10.00	D=.0194169	V= 1.22	A=76.650		19	
SISKIND GROUP	169	THRESHOLD	F=12.50	D=.0268654	V= 2.11	A=165.71		51	
SISKIND GROUP	170	THRESHOLD	F=16.00	D=.0282500	V= 2.84	A=285.50		51	
SISKIND GROUP	171	THRESHOLD	F=20.00	D=.0098676	V= 1.24	A=155.82		51	
SISKIND GROUP	173	THRESHOLD	F=24.00	D=.0063662	V= 1.01	A=144.76		51	
SISKIND GROUP	174	THRESHOLD	F=14.00	D=.0211449	V= 1.86	A=163.61		51	
SISKIND GROUP	176	THRESHOLD	F=14.00	D=.0634346	V= 5.58	A=490.84		51	
SISKIND GROUP	177	THRESHOLD	F=15.00	D=.0413803	V= 3.90	A=367.56		51	
SISKIND GROUP	178	THRESHOLD	F=25.00	D=.0066208	V= 1.04	A=163.36		51	
SISKIND GROUP	179	THRESHOLD	F=25.00	D=.0157245	V= 2.08	A=387.98		51	
SISKIND GROUP	182	THRESHOLD	F=12.00	D=.0844848	V= 6.37	A=480.28		51	
SISKIND GROUP	203	THRESHOLD	F=22.00	D=.0097663	V= 1.35	A=186.61		58	
SISKIND GROUP	204	THRESHOLD	F=22.00	D=.0161325	V= 2.23	A=308.25		58	
SISKIND GROUP	205	THRESHOLD	F=19.00	D=.0165856	V= 1.98	A=236.37		58	
SISKIND GROUP	207	THRESHOLD	F=18.00	D=.0166228	V= 1.88	A=212.62		58	
SISKIND GROUP	208	THRESHOLD	F=12.40	D=.0186108	V= 1.45	A=112.97		58	

3 SISKIND GROUP MINOR DAMAGE DATA POINTS

SISKIND GROUP	175	MINOR DAMAGE	F=12.50	D=.1299978	V=10.21	A=801.89	51
SISKIND GROUP	180	MINOR DAMAGE	F=11.00	D=.1530781	V=10.58	A=731.23	51
SISKIND GROUP	181	MINOR DAMAGE	F=11.00	D=.1048976	V= 7.25	A=501.08	51

* NOT USED IN ANALYSES IN RI 8507

25 SISKIND GROUP NONDAMAGE DATA POINTS

SISKIND GROUP	47	NONDAMAGE	F=29.40	D=.0012992	V= .24	A=44.330	STRUCTURE #	19	ADDITIONAL B.M. DATA
SISKIND GROUP	47	NONDAMAGE	F=25.00	D=.0016552	V= .26	A=40.840		19	
SISKIND GROUP	47	NONDAMAGE	F=16.70	D=.0027637	V= .29	A=30.420		19	
SISKIND GROUP	81	NONDAMAGE	F=11.60	D=.0032928	V= .24	A=17.490		19	
SISKIND GROUP	81	NONDAMAGE	F=11.90	D=.0046810	V= .35	A=26.160		19	
SISKIND GROUP	103	NONDAMAGE	F=31.30	D=.0013729	V= .27	A=53.090		22	
SISKIND GROUP	103	NONDAMAGE	F=35.70	D=.0023628	V= .53	A=118.88		23	
SISKIND GROUP	103	NONDAMAGE	F=21.70	D=.0055740	V= .76	A=103.62		23	
SISKIND GROUP	107	NONDAMAGE	F=22.00	D=.0014468	V= .20	A=27.640		26	
SISKIND GROUP	107	NONDAMAGE	F=23.00	D=.0017991	V= .26	A=37.570		26	
SISKIND GROUP	108	NONDAMAGE	F=14.30	D=.0026711	V= .24	A=21.560		28	
SISKIND GROUP	108	NONDAMAGE	F=16.70	D=.0019060	V= .20	A=20.980		28	
SISKIND GROUP	116	NONDAMAGE	F=17.90	D=.0020450	V= .23	A=25.860		31	
SISKIND GROUP	116	NONDAMAGE	F=14.30	D=.0024485	V= .22	A=19.760		31	
SISKIND GROUP	134	NONDAMAGE	F=11.10	D=.0040147	V= .28	A=19.520		33	
SISKIND GROUP	157	NONDAMAGE	F=12.50	D=.0056022	V= .44	A=34.550		46	
SISKIND GROUP	158	NONDAMAGE	F=20.00	D=.0032626	V= .41	A=51.520		46	
SISKIND GROUP	158	NONDAMAGE	F=20.00	D=.0025464	V= .32	A=40.210		46	
SISKIND GROUP	158	NONDAMAGE	F=14.30	D=.0027824	V= .25	A=22.460		46	
SISKIND GROUP	159	NONDAMAGE	F=38.00	D=.0013821	V= .33	A=78.790		46	
SISKIND GROUP	159	NONDAMAGE	F=29.40	D=.0012992	V= .24	A=44.330		46	
SISKIND GROUP	159	NONDAMAGE	F=20.00	D=.0026260	V= .33	A=41.460		46	
SISKIND GROUP	160	NONDAMAGE	F=21.70	D=.0021269	V= .29	A=39.540		47	
SISKIND GROUP	160	NONDAMAGE	F=18.50	D=.0019786	V= .23	A=26.730		47	
SISKIND GROUP	172	NONDAMAGE	F=13.90	D=.0022899	V= .20	A=17.460		49	

76 SISKIND GROUP NONDAMAGE DATA POINTS

NEW B.M. DATA

								STRUCTURE #
SISKIND GROUP	47	NONDAMAGE	F=15.20	D=.0115178	V=	1.10	A=105.05	20
SISKIND GROUP	49	NONDAMAGE	F=15.80	D=.0024175	V=	.24	A=23.820	20
SISKIND GROUP	49	NONDAMAGE	F=15.90	D=.0033241	V=	.33	A=32.760	20
SISKIND GROUP	49	NONDAMAGE	F=18.80	D=.0028783	V=	.34	A=40.160	20
SISKIND GROUP	50	NONDAMAGE	F=12.80	D=.0031084	V=	.25	A=20.100	20
SISKIND GROUP	50	NONDAMAGE	F=15.90	D=.0026190	V=	.26	A=25.810	20
SISKIND GROUP	51	NONDAMAGE	F=14.10	D=.0025961	V=	.23	A=20.370	20
SISKIND GROUP	51	NONDAMAGE	F=20.80	D=.0018364	V=	.24	A=31.360	20
SISKIND GROUP	55	NONDAMAGE	F=19.80	D=.0017683	V=	.22	A=27.360	20
SISKIND GROUP	55	NONDAMAGE	F=18.80	D=.0026244	V=	.31	A=36.610	20
SISKIND GROUP	56	NONDAMAGE	F=19.80	D=.0020095	V=	.25	A=31.100	20
SISKIND GROUP	81	NONDAMAGE	F=13.90	D=.0051525	V=	.45	A=39.300	19
SISKIND GROUP	82	NONDAMAGE	F=11.30	D=.0278873	V=	1.98	A=140.58	19
SISKIND GROUP	99	NONDAMAGE	F=12.00	D=.0034483	V=	.25	A=19.600	21
SISKIND GROUP	99	NONDAMAGE	F=31.00	D=.0015915	V=	.31	A=60.380	21
SISKIND GROUP	100	NONDAMAGE	F=28.00	D=.0055135	V=	.97	A=170.65	21
SISKIND GROUP	100	NONDAMAGE	F=25.00	D=.0066845	V=	1.05	A=164.93	21
SISKIND GROUP	102	NONDAMAGE	F=31.00	D=.0056987	V=	1.11	A=216.20	21
SISKIND GROUP	102	NONDAMAGE	F=23.00	D=.0090649	V=	1.31	A=189.31	21
SISKIND GROUP	103	NONDAMAGE	F=36.00	D=.0036251	V=	1.82	A=185.47	23
SISKIND GROUP	103	NONDAMAGE	F=33.00	D=.0015433	V=	.32	A=66.350	22
SISKIND GROUP	104	NONDAMAGE	F=22.00	D=.0078854	V=	1.09	A=150.67	23
SISKIND GROUP	104	NONDAMAGE	F=11.90	D=.0054834	V=	.41	A=130.65	22
SISKIND GROUP	104	NONDAMAGE	F=22.70	D=.0053986	V=	.77	A=109.82	23
SISKIND GROUP	104	NONDAMAGE	F=50.00	D=.0014005	V=	.44	A=138.23	23
SISKIND GROUP	104	NONDAMAGE	F=11.90	D=.0031830	V=	.22	A=115.20	22
SISKIND GROUP	105	NONDAMAGE	F=38.00	D=.0025548	V=	.61	A=145.64	23
SISKIND GROUP	105	NONDAMAGE	F=39.00	D=.0017139	V=	.42	A=102.91	23
SISKIND GROUP	105	NONDAMAGE	F=31.00	D=.0043639	V=	.85	A=165.56	23
SISKIND GROUP	106	NONDAMAGE	F=20.00	D=.0015120	V=	.19	A=23.870	25
SISKIND GROUP	107	NONDAMAGE	F=23.00	D=.0017991	V=	.26	A=37.570	26
SISKIND GROUP	108	NONDAMAGE	F=20.00	D=.0016711	V=	.21	A=26.380	28
SISKIND GROUP	110	NONDAMAGE	F=55.00	D=.0029516	V=	1.02	A=352.48	21
SISKIND GROUP	110	NONDAMAGE	F=17.00	D=.0048686	V=	.52	A=55.540	21
SISKIND GROUP	110	NONDAMAGE	F=15.00	D=.0141117	V=	1.33	A=125.34	21
SISKIND GROUP	111	NONDAMAGE	F=29.00	D=.0018659	V=	.34	A=61.950	21
SISKIND GROUP	111	NONDAMAGE	F=16.00	D=.0068635	V=	.69	A=69.650	21
SISKIND GROUP	111	NONDAMAGE	F=14.00	D=.0089809	V=	.79	A=69.490	21
SISKIND GROUP	112	NONDAMAGE	F=19.20	D=.0032328	V=	.39	A=47.040	30
SISKIND GROUP	112	NONDAMAGE	F=17.90	D=.0017782	V=	.20	A=22.490	30
SISKIND GROUP	112	NONDAMAGE	F=18.50	D=.0036993	V=	.43	A=49.980	30
SISKIND GROUP	113	NONDAMAGE	F=18.50	D=.0038713	V=	.45	A=52.300	21
SISKIND GROUP	113	NONDAMAGE	F=18.50	D=.0028389	V=	.33	A=38.350	21
SISKIND GROUP	113	NONDAMAGE	F=17.00	D=.0064598	V=	.69	A=73.700	21
SISKIND GROUP	114	NONDAMAGE	F=12.20	D=.0061313	V=	.47	A=36.020	21
SISKIND GROUP	114	NONDAMAGE	F=25.00	D=.0029920	V=	.47	A=73.820	21
SISKIND GROUP	114	NONDAMAGE	F= 9.60	D=.0084551	V=	.51	A=30.760	21
SISKIND GROUP	116	NONDAMAGE	F=15.00	D=.0025465	V=	.24	A=22.620	31
SISKIND GROUP	125	NONDAMAGE	F=16.00	D=.0020889	V=	.21	A=21.110	33
SISKIND GROUP	134	NONDAMAGE	F= 6.30	D=.0080841	V=	.32	A=12.660	33
SISKIND GROUP	135	NONDAMAGE	F=29.00	D=.0054881	V=	1.00	A=182.21	21
SISKIND GROUP	135	NONDAMAGE	F=71.00	D=.0020622	V=	.92	A=410.41	21
SISKIND GROUP	135	NONDAMAGE	F=22.00	D=.0082471	V=	1.14	A=157.58	21
SISKIND GROUP	136	NONDAMAGE	F=25.00	D=.0098039	V=	1.54	A=241.90	21
SISKIND GROUP	136	NONDAMAGE	F=33.00	D=.0054061	V=	1.12	A=232.22	21
SISKIND GROUP	136	NONDAMAGE	F=62.00	D=.0040816	V=	1.59	A=619.40	21
SISKIND GROUP	146	NONDAMAGE	F=11.10	D=.0031544	V=	.22	A=15.340	17
SISKIND GROUP	154	NONDAMAGE	F=16.10	D=.0033610	V=	.34	A=34.390	43
SISKIND GROUP	154	NONDAMAGE	F=14.20	D=.0057161	V=	.51	A=45.500	43
SISKIND GROUP	155	NONDAMAGE	F=20.00	D=.0034218	V=	.43	A=54.030	44
SISKIND GROUP	155	NONDAMAGE	F=22.00	D=.0039789	V=	.55	A=76.020	44
SISKIND GROUP	156	NONDAMAGE	F=22.00	D=.0041235	V=	.57	A=78.790	44
SISKIND GROUP	156	NONDAMAGE	F=22.00	D=.0069449	V=	.96	A=132.70	44
SISKIND GROUP	161	NONDAMAGE	F=29.00	D=.0035123	V=	.64	A=116.61	48
SISKIND GROUP	161	NONDAMAGE	F=33.00	D=.0030866	V=	.64	A=132.70	48
SISKIND GROUP	161	NONDAMAGE	F=33.00	D=.0056428	V=	1.17	A=242.59	48
SISKIND GROUP	165	NONDAMAGE	F= 8.30	D=.0047938	V=	.25	A=13.030	49
SISKIND GROUP	165	NONDAMAGE	F=12.50	D=.0045837	V=	.36	A=28.270	49
SISKIND GROUP	166	NONDAMAGE	F=31.00	D=.0010268	V=	.20	A=38.950	49
SISKIND GROUP	167	NONDAMAGE	F=18.50	D=.0036132	V=	.42	A=48.820	51
SISKIND GROUP	167	NONDAMAGE	F=23.80	D=.0022067	V=	.33	A=49.340	51
SISKIND GROUP	167	NONDAMAGE	F=25.00	D=.0031831	V=	.50	A=78.540	51
SISKIND GROUP	168	NONDAMAGE	F=25.00	D=.0054112	V=	.85	A=133.51	51
SISKIND GROUP	168	NONDAMAGE	F=25.00	D=.0045836	V=	.72	A=113.09	51
SISKIND GROUP	168	NONDAMAGE	F=25.00	D=.0073848	V=	1.16	A=182.21	51
SISKIND GROUP	172	NONDAMAGE	F=25.00	D=.0013369	V=	.21	A=32.980	20

Bureau of Mines
Report of Investigations 8507

STRUCTURE RESPONSE AND DAMAGE PRODUCED
BY GROUND VIBRATION FROM SURFACE
MINE BLASTING

by

David E. Siskind, Mark S. Stagg, John W. Kopp,
and Charles H. Dowding

ERRATA

Page 1, Line 14 should read "Safe levels" instead of "Save levels."

Page 3, footnote should read "Italic numbers" instead of "Underlined numbers."

Page 12 (table 1): Six shots had been omitted are given on the attached page. In addition, shot 134, "Peak ground vibration (H_2)" should be 0.32 instead of 0.36, and the column heading labeled "Sealed distance" should read "Scaled distance."

Page 19 (equation 2): Sign before $\frac{\beta}{\sqrt{1 - \beta^2}}$ should be minus instead of plus.

Page 23 (table 2): Houses numbered 58 and above have some of the shots improperly. indicated. The attached table shows the correct values, and is consistant with table 1.

Page 28 (figure 28): Caption should read "Test structure 61, near a construction site."

Page 41 (table 5): Footnote number 4 should show 119dB airblast instead of 111dB.

Page 42 (table 6): Values in "Mine blasts" column should read .377 instead of .472 and .314 instead of .392. Footnote number 1 should have 119dB airblast instead of 111dB.

Page 48 (table 9): Jensen and Rietman reference number should be 21 instead of 57. Also, number of Non-damage and Threshold values for "Bureau of Mines new data" should be 76 and 28, respectively, not 37 and 23.

Page 71 (table A-2): Values in the "Granite, hard limestone, or diabase" column should be as follows:

mm/sec	in/sec
70	2.8
110	4.3
160	6.3
230	9.1

ADDITIONAL VALUES FOR TABLE 1 OF RI 8507

Production blasts and ground vibration measurements

Shot	Facility	Shot type	Total charge lb.	Lb per delay	Scaled distance ft/lb 1/2	Peak ground vibration, in/sec			Peak structure motion, in/sec								Structure number (table 3)	Structure type
									Low corner			High corner		Midwall				
						H_1	H_2	V	H_1	H_2	V	H_1	H_2	H_1	H_2			
155	Coal	Highwall..	5,400	120	43.0		0.43	0.55						0.84			44	1
156	Coal	....do....	3,600	80	41.0		0.96	0.57						0.76			44	1
173	Coal	....do....	2,150	86	27.0	0.59	0.96	1.01	0.56	0.66	1.19			0.74	2.55		51	2
176	Coal	....do....	3,550	71	6.9	5.58	2.34	2.61	2.85	1.32	4.09	3.43	1.41	9.14	2.69		51	2
177	Coal	....do....	3,240	36	9.7	3.90	2.44	1.65	2.13	2.2	2.60	3.53	2.28	7.06	2.82		51	2
209	Coal	....do....		80	19.0	4.50	1.17	1.60									58	1
W-17	Constr	Excavation	50	13	1.4	5.83	11.87	6.49	8.05	2.08	9.62	2.77	2.03	5.8	8.69		67	2

CORRECTIONS FOR TABLE 3 OF RI 8507

Test structures and measured dynamic properties

Structure	Shots (table 1)
57	201,202
58	203-209
59	W-1
60	W-2, W-3
61	W-4, W-5
62	W-6
63	W-7, W-8
64	W-9, W-10
65	W-11, W-12
66	W-13, W-14, W-15
67	W-16, W-17
68	W-18, W-19
69	W-20, W-21
70	W-22
71	W-23
72	W-24
73	W-25, W-26, W-27
74	W-28, W-29
75	W-30
76	W-31, W-32