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 158-144

30272-101		1. REPORT NO. CISST 4/81		2.		3. Recipient's Accession No.	
REPORT DOCUMENTATION PAGE							
4. Title and Subtitle Social, Economic and Legal Consequences of Blasting in Strip Mines and Quarries				5. Report Date May 31, 1981		6.	
7. Author(s) Michael Radnor, Principal Investigator Durward Hofer, Project Leader				8. Performing Organization Rept. No. 6065-406			
9. Performing Organization Name and Address Northwestern University Center for the Interdisciplinary Study of Science and Technology 626 Library Place Evanston, IL 60201				10. Project/Task/Work Unit No.		11. Contract(C) or Grant(G) No. (C) J0285036 (G)	
12. Sponsoring Organization Name and Address United States Department of the Interior Bureau of Mines Twin Cities Mining Research Center P.O. Box 1660. Minneapolis. Minn. 55111				13. Type of Report & Period Covered Research 6/30/78 - 5/31/81		14.	
15. Supplementary Notes Other authors: Catherine Aimone, Dimitrios Atmatzidis, Richard Lamm, Sumantra Mukherji, Elizabeth Olmsted, Regan Romei							
16. Abstract (Limit 200 words) The purpose of the study was to 1) examine the social and economic impacts of surface mine blasting in relation to variations in conditions of terrain and geology, population density and type, levels of ground motion and air blast; 2) consider technical, legal and government policy issues; and 3) examine the potential, nature and extent of surface mine blasting impacts and its regulations upon both communities and surface mining companies. Phase One designed the empirical research and technical analyses of Phase Two, focused upon surface coal mining and quarrying in the Eastern U.S. Several broad conclusions are evident: 1) blasting is not the major issue for communities or surface mine companies; 2) while the number of instances of severe cracking or annoyance are relatively small, the impact can be severe for individuals immediately involved; 3) blasting/drilling cost curves tend to rise significantly at intervals below 1.0 particle velocity, in/sec, dependent upon the size of a permit area and the size of a mine; and 4) the legal, complaint, cost and density analyses do not suggest the need for a general lowering of present regulations.							
17. Document Analysis a. Descriptors Regulation. Policy. Surface-Mining. Sociology. Economics. Law. Ground-Motion. Air-Blast. Terrain. Geology. Population. Quantative-Assesment. Strip-mining. Blasting. Environmental-impact. Quarrying. b. Identifiers/Open-Ended Terms Office of Surface Mining. U.S. Bureau of the Mines c. COSATI Field/Group Mining. Economics. Regulation. Law. Sociology							
18. Availability Statement Release unlimited				19. Security Class (This Report) Unclassified		21. No. of Pages 335	
				20. Security Class (This Page) Unclassified		22. Price	

(See ANSI-Z39.18)

See Instructions on Reverse

OPTIONAL FORM 272 (4-77)
 (Formerly NTIS-35)
 Department of Commerce

FOREWORD

This report was prepared by Northwestern University Center for the Interdisciplinary Study of Science and Technology under USBM Contract number JO 285036. The contract was initiated under the Twin Cities Mining Research Center Program. It was administered under the technical direction of the Bureau of the Mines, with Dr. David Siskind acting as Technical Project Officer. David J. Askin was the contract administrator for the Bureau of Mines. This report is a summary of the work recently completed as a part of this contract during the period June 30, 1978 to May 31, 1981. This report was submitted by the authors on May 31, 1981.

We wish to recognize a number of people who gave us enormous assistance in carrying out this study and in preparing the report.

First and foremost, we wish to thank Professor Charles Dowding of Northwestern University's Civil Engineering Department. Chuck was involved in every step from the very initiation of the project to its conclusion. Even though his role was as an unpaid and unofficial consultant, he made enormous and continuing contributions. The project could not have been carried out as it was without his valuable help.

We also wish to recognize the advice of our advisory panel in the early phases of the project. Their critical comments were vital in pointing us in the right direction.

We also thank the many people — citizens, mining and government officials, etc. — who gave us their valuable time and cooperation. We hope that the findings will prove beneficial to these people, those ultimately involved.

Finally, we must recognize the assistance and guidance we received from the Bureau of Mines staff with whom we worked: Dr. David Siskind, Dr. Richard Dick, Dr. Egons Podnieks. Their advice, critiques and patience were important contributions to our effort.

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The Northwestern University research team was supported by:

Subcontractors

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VME-Nitro Consult, Inc.

and by an:

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**EXECUTIVE SUMMARY
AND
OVERVIEW**

Under contract No. J0285036 with the U.S. Bureau of Mines of the Interior Department, the Northwestern University Center for the Interdisciplinary Study of Science and Technology (CISST) undertook a study to: 1) examine the social and economic impacts of surface mine blasting in relation to variations in conditions of terrain and geology, population density and type, levels of ground motion (in/sec) and air blast (dB), blasting technology; 2) consider technical, legal and government policy issues; and 3) examine the potential, nature and extent of surface mine blasting impacts and its regulations upon both communities and surface mining companies. This report presents the results of this study.

The study focused upon surface coal mining in the Eastern region of the United States, with attention also being given to quarrying. Analysis during Phase One of the study* indicated that given the nature and design of this study, the findings would for the most part be generalizable to other surface mining/blasting operations. The results of the Phase Two research reinforce this conclusion.**

Concern about the impacts of surface mine blasting have been expressed by a variety of parties, including both citizens, mining companies and government agencies. Not surprisingly, various parties have viewed the issue of blasting impacts (as well as the process of control and regulation) from different perspectives. Further, while there has been research relevant to the issue, it is reasonable to state that the bulk of such research has focused on technical rather than social and economic concerns. This study has attempted to take into account: the perspectives and concerns of different parties; a wide range of variables (and types of impacts) and the nature of their interaction; and benefits as well as costs to both the community and to mining companies. Thus, the study has viewed the issue as a chain of blasting impacts and social/economic consequences, as illustrated in Figure 1.

The study was conducted in two phases. The purpose of Phase One was to design the empirical research and technical analyses of Phase Two. Thus, Phase One included: a full-day workshop with a panel representing the perspectives and expertise of various concerned parties, field testing of social, legal and technical/cost research

* See the Phase One Report.

** There will of course be contextual factors which must be considered whenever one attempts to generalize from one context to another. In particular for this study, consideration would need to be given to possible differences across surface mining/blasting industries with regard to industry infrastructure, community cultures and population densities. Nonetheless, the basic findings of this study should have a high degree of generalizability.

designs; and the development of a comprehensive list of variables and indicators for the empirical research in Phase Two.*

Phase Two consisted of a series of empirical studies and technical analyses. Field research teams collected on-site data from mine companies, local communities and government agencies in a selected representative sample** of eight counties in eight states. Sites for the legal/formal complaint analysis were selected from the above eight counties. Additionally, seven other sites were chosen for field research on property values around quarries in city/metropolitan areas. A sample of current (1978-9) surface mine permits were analyzed for density patterns. In addition to the above, technical analyses were developed concerning (1) annoyance and (2) damage classification.

A summary of the findings is provided below, with more comprehensive discussion provided in Section One and Two of this report.

* These are provided in the Phase One report.

** The criteria and process for site selection are discussed in Section One.

I. BLASTING AS AN ISSUE: GAINING PERSPECTIVE

Several broad conclusions become immediately evident from this study.

- 1) Blasting per se is not the major issue either for communities near surface mines or for the surface mine companies.
- 2) The number of instances where severe cracking or annoyance impacts on community do occur is quite small relative to the total number of mines, the total number of blasts, or to the total number of residents near surface mines. Nonetheless, where such instances do occur, the impact can be quite severe for community residents who are immediately involved.
- 3) Blasting/drilling cost curves tend to rise significantly at intervals below 1.0 particle velocity, in/sec. Of course, the level of particle velocity required at the point of a blast to insure 1.0 or less particle velocity at a structure away from the blast will depend on the distance between the blast site and the structure. Thus, it follows that cost curves at intervals below 1.0 particle velocity are inversely related to the size of a permit area. It further follows that the cost impact will tend to be more significant for small than for large mines; and in steep or sloping terrains (which tend to have smaller permit areas). The overall cost impact will tend to be least in flat terrains characterized by large permit areas.
- 4) The legal, complaint, cost and density analyses of this study do not suggest a general across-the-board lowering of regulations below 1.0 particle velocity, in/sec. However, there are unique situations where policy and regulatory flexibility may be needed in this regard.

As part of this study, an analysis was made of complaints made by community residents.* This analysis reveals that community residents complain about a variety of mining-related (and non-blasting related) impacts such as: truck-related impacts such as noise, dust and road or property damage; reclamation concerns; water related concerns such as flooding and water quality of streams and lakes; roads blocked from mud slides. Further, the analysis of these complaints (and of other interviewee comments) reveals that non-blasting related complaints are more prevalent than are blasting related complaints, though of course this may vary across specific surface mine companies and operations.

When the impacts of blasting are more direct, as for example, cracking, it is often difficult to determine whether cracking resulted from

* Community residents lodge complaints in a variety of ways, both formal and informal. These modes of the complaint process include: filing of lawsuits and the lodging of formal complaints with governmental regulatory agencies; the lodging of complaints with other governmental agencies such as the County Sheriff's Department or the County Commissioners; complaints made directly to the mine; complaints made to and by voluntary community organizations; or even the informal directing of "complaints" to bank personnel, Chambers of Commerce, realtors, and so on.

blasting or from some other source, such as improper construction of structures, settling of ground underneath a structure, or some combination of these conditions and the blasting. Methods that do exist for determination of blasting as a cause of cracking are probabilistic, complicated and costly if used extensively. Similarly, blasting related annoyance complaints are affected by such factors as varying tolerance levels of individuals, community norms and cultures, etc.

From the above considerations, it is concluded that in a relative sense, blasting as an issue is subordinate to the larger issues of the impacts of surface mining in general and of reclamation in particular. Further, this study has found that even when blasting does impact a community, the impact is the result of a specific constellation of conditions or factors present in that particular site or context.

The above findings have focused on the impact of blasting on communities. Consideration must also be given to the impact of regulations on mine companies. This study has found that while mine companies have generally been able to modify their blasting processes so as to meet the 1.0 in/sec. regulation without major cost impact, lowering of the regulatory limit below 1.0 in/sec could result in significant cost increases except in those cases where the permit area is quite large — a condition more prevalent in flat terrains than in steep or sloping terrains.* This study has further found that while mine operators are concerned about the costs associated with blasting regulations, they are far more concerned about reclamation costs. A similar preponderance of concern about reclamation versus concern about blasting is found in review of newspaper articles (national and local) and of various Federal, state and private publications.

The above discussion sets the blasting impact issue in proper perspective relative to the total enterprise of surface mining in which blasting occurs; namely, that blasting per se is not the major issue.

It now becomes important to identify the ways in which the impacts of blasting are or can be of significant concern. These three points will suffice.

First, where levels of ground vibration, air blast and especially fly-rock are very high, impacts can indeed be severe for community residents who are close to the blast site. Flyrock in particular can pose a severe threat not only to the property but also to the health of nearby community residents. Thus, while the total number of severe blasting impacts may be relatively few, the impact can indeed be major for those actually affected. In such cases, the severity of impact neither can nor should be down-played.

Second, the findings of this study strongly suggest that instances of severe blasting impact are for the most part the result of poor quality

* This conclusion assumes current state-of-the-art in equipment and methodology.

of blasting practice. The state of the art for blasting technology is quite adequate to meet current Federal blasting regulations and therefore to maintain control in most situations of particle velocity, dB and fly-rock at levels sufficient to prevent severe blasting impacts. Both the current state of the art and the data collected during the field research lead us to conclude that the primary cause of severe blasting impacts is the inability and/or unwillingness of a particular mine company or blasting crew to use current state of the art blasting technology and design.

Third, the analysis suggests that while costs of reclamation are a larger issue for mine companies than blasting costs, there are nonetheless significant cost increases associated with decreasing levels of particle velocity, especially levels below the currently mandated 1.0 in/sec.

The findings of this study do not suggest a need for lowering particle velocity regulations below the current 1.0 in/sec. Rather, this study suggests the need for a flexible and integrated portfolio of policies and programs which ensures both the enforcement of and the capability of mine companies to comply with current regulations.

The sections which follow summarize in more detail the findings of this study.

II. BLASTING IMPACT ON COMMUNITY

This study treated blasting impact on community* as a unitary concept having three interactive dimensions:

- 1) The direct impacts of cracking and annoyance which result from ground vibration, air blast or flyrock.
- 2) Community awareness of blasting as an issue--i.e., the extent to which there is a perception or belief among community residents that blasting is having an impact on their community, and the perceived level and the kind of impact.
- 3) Community response to blasting impact on community--i.e., whether, to what extent, and in what ways members of the community take action to deal with and/or reduce blasting impact on community.

Community awareness and response are included in the impact because they are important dimensions of the blasting issue and because they result from the belief that cracking and annoyance have resulted from blasting. Awareness and response are treated separately because awareness is a precursor and requirement of response and because response is not necessarily predetermined by a particular level of awareness.

* The term "impact on community" is used to simplify reference to a variety of impacts and a range from impact on an individual to impact on an entire community.

A. The Potential for Impact on Community

To what extent there is a potential for the direct impacts of cracking and annoyance is directly related to the factors of distance and density moderated by levels of particle velocity, dB and flyrock. This is a logical deduction from technical considerations. Thus, at one extreme there is by definition no potential for impact if there are no people or structures (density) within the technical range (distance) of ground vibration, airblast or flyrock. At the other extreme, there would be a large potential for impact if there were a large concentration of people or structures within very close proximity of a blast site. However, even under this condition, to what extent actual cracking or annoyance would occur would depend on the physical conditions of the site and on the control exercised through blasting design to reduce levels of vibration, air blast and flyrock.

Analysis of density and distance patterns in surface coal mining areas suggests that in general, the potential for blasting impact on community is quite low. For example, analysis of a sample of current (1978-79) surface coal mining permit areas indicates that within 500 feet of permit boundaries, there would be:

- 1) an average of 2.302 houses;*
- 2) an 81.2% probability that there would be five houses or less;
- 3) a 38.6% probability that there would be no houses.

Similarly, analysis of the coal producing counties in the eastern half of the United States reveals that population density of these counties** ranges from 16 to 578 persons/square mile, with the ratio being less than 100 persons/square mile in 79.1% of the counties and 50 or less persons/square mile in 47.1% of the counties. Further the analysis of density around current permit areas revealed town/city boundaries overlapping a 5,000 foot radius of the permit boundary in only 5 of 101 cases. Thus, both demographic analysis and the field research indicate that Eastern surface mines are generally located in relatively isolated areas.*** This is certainly even more the case for Western U.S. mines.

It is true, of course, that some mines are located near more densely populated areas ranging from relatively small clusters of homes to towns or cities whose boundaries fall within 5,000 feet or less of mine permit boundaries. Three brief points are to be made here.

* Adjusted mean for 95% of all cases examined, omitting extreme jumps in value.

** 1975 estimates.

*** The counties include both surface and underground mines.

First, such instances of high population density near mine permit boundaries are relatively scarce, as is noted above.

Second, the analysis of current permit areas suggests that unincorporated clusters of houses tend to be located in the more distant 2,500-5,000 foot range from the permit boundary.

Third, despite the relatively small rate of occurrence, analysis does suggest that the presence of a major metropolitan area (core city of at least 100,000 population) does tend to affect the social impact of blasting. This is noted in more detail later.

The Table below reflects the density patterns for houses represented in an analysis of a sample of current (1978-79) permit areas.

Statistics	Zones				
	1	2	3	4	5
Mean	0.465	3.099	5.089	21.307	41.681
Adjusted Mean	0.465	2.302	3.495	17.021	35.122
Standard Deviation	1.188	4.631	7.575	25.255	44.119
Adjusted Standard Deviation	1.188	3.078	3.789	16.956	31.402
Median	0.131	1.219	2.333	13.556	28.500
Adjusted Median	0.131	1.063	2.133	12.167	26.500
Range	6.000	21.000	41.000	124.000	222.000
Adjusted Range	6.000	15.000	14.000	74.000	138.000

Zone 1: Within permit boundaries
 Zone 2: Within 500' of permit boundaries
 Zone 3: Within 500'-1000' of permit boundaries
 Zone 4: Within 1000'-2500' of " "
 Zone 5: Within 2500'-5000' of " "

B. Complaints and Lawsuits--Indicators of Actual Blasting Impacts

In attempting to answer the question of the level and nature of actual blasting impact on community, two initial observations must be made. First, since the data base is not adequate an absolute answer cannot be given. In the majority of instances of alleged blast-induced cosmetic and load loss cracking*, pre-blast data are absent (or in some cases of questionable value), and post-blast crack origination estimation techniques either are not employed in any systematic manner or are vague and questionable in nature.** Thus, in all but the most clear-cut cases, these data inadequacies make it difficult at best and in many instances impossible to determine if cracking was induced by blasting or by any of a number of other possible causes. Furthermore, while the use of pre-blast data combined with site data obtained during a blast would greatly increase our level of certainty as to cause of cracking, determination of crack origination remains probabilistic in nature. The methods which would increase our level of certainty the most (e.g.: use of pre-blast photographs and measurement of structural stress responses to blast-related vibrations) are costly and are not likely to become widespread in usage.

Second, both the inadequacy of the primary data base and the magnitude of cost and time which would be required, make it impractical to attempt a case-by-case examination of all possible cases of alleged blast-induced impacts on community. Thus, it is necessary to rely on indicators of the nature and levels of actual impacts. For this purpose, the following were examined: 1) lawsuits at the state or appellate levels; 2) formal complaints to state regulatory agencies; and 3) complaints to other organizations as local institutions (e.g.: Chambers of Commerce, newspapers, banks), local governmental agencies (e.g.: county sheriffs, county commissioners), local community groups, or directly to mine personnel.

It is to be noted that various sources of complaint data must be utilized in order to avoid misinterpretation. For example, examination only of court cases might lead one to the conclusion that actual blasting impacts on community are extremely rare (relative to the total number of mines and of blasts performed in these mines). Contrarily, consideration only of complaints made directly to mine companies could lead to an overly exaggerated estimation of actual blasting impact on community.

Several aspects of the overall complaint process are worth noting here.

* The reasons for use of the terms "cosmetic and load loss cracking" are discussed later.

** As is noted later, there is currently no consensus as to crack origination estimation techniques, especially for post facto determination.

First, it is to be noted that lawsuits and/or formal complaints represent only a part of the total complaint process—and except where large numbers of these are found (which was not typically found in this study), are not necessarily adequate indicators of either complaint/impact levels or of the adequacy of the complaint process. For example, citizens may not use these formal complaint mechanisms for such reasons as: cost of the legal process; the disaggregatedness of complaint mechanisms across several regulatory agencies; newness of a regulatory agency (as in the case of OSM); geographical distance from a regulatory agency; factors related to community culture.

Second, there are a number of informal mechanisms which citizens use to attempt a resolution of alleged blasting impacts. These may range from direct contact with mine personnel; to complaints being made to local government officials or to local business leaders; or to the use of community action groups. It is to be noted that both the type of informal mechanisms used and the extent of their use tends to vary across communities. For example, in one county, the county sheriff accepted the role of "complaint receiver", while in another county the sheriff clearly eschewed this role.

Third, in some communities there appear to be tacit but well-understood modus operandi between mines and a local community concerning the process for resolving blast-related complaints. The nature and existence of these understandings vary across communities and appear to depend primarily on the overall nature of mine-community interaction and on the presence of an historically developed mining culture.

Fourth, analysis of state appellate and federal court cases reveals an emphasis on three main issues of law: 1) strict liability vs. negligence; 2) measurement of appropriate amount of recovery; and 3) causation. Analysis of state trial cases reveals a general lack of patterns in cases filed, and also a relatively small number of cases. Trends and patterns were also difficult to discern in complaints to state regulatory agencies—though here the inadequacies of the available data base made analysis quite difficult.

C. Variation in Levels and Kinds of Blasting Impact on Community

Variation in levels and kinds of blasting impacts on community was found along several dimensions. For example:

- * In several of the field research sites*, the overall level of formal and/or informal complaints about blasting impacts was generally low. Nonetheless, in each of these sites there were scattered instances of alleged blast-induced cosmetic or structural cracking. In most cases, the severity of alleged cracking in terms of cost of repair was relatively small. However, in two instances involving nearby houses, community residents spoke in terms of "blowing off the side of the mountain" and "destroying their property".
- * The nature of alleged blast-induced impacts ranged from cracking of walls and wells, to lowering of water levels in wells, to annoyance for persons who work nights and sleep days.
- * Community residents distinguished between fly-by-night firms to which they attributed significant and continuous levels of blasting impacts, and respected firms which generally do not impact communities by blasting, though even here, an occasional blowout was noted by residents and in one special situation a consistent complaint pattern was observed.
- * Communities differed significantly in the levels of blasting impacts which were considered "acceptable" or "tolerable".
- * Proximity to mines does not correlate directly with levels of complaints about blasting. Complaints were noted at distances from mines ranging from below 500' to more than three miles. Both the presence and absence of complaints were noted where residents were in close proximity to mines.
- * In a similar vein, both the presence and absence of complaints were noted in cases of documented 2.0, 1.0 and other in/sec levels.
- * High levels of complaints were noted at sites having dissimilar characteristics. For example, in one site residences were at varying distances up to a mile from the mine and a high level of quality of blasting practice was observed. In a second site, residences three miles from a quarry and instances of poor quality of blasting practice were observed.

* "Sites" refers here to the eight counties selected for the primary field research.

- * Such factors as size of mine, type of terrain, basic mining method, region of the country, etc. do not directly correlate with variation in levels of blasting impact.

In a word, variations in blasting impacts do exist. While severe cracking impacts do not appear to be common, they occasionally do occur. Levels of complaints vary across sites, across mines, across individuals and groups in a community.

D. A Constellation of Factors Affecting the Level of Blasting Impact

Analysis of variation in blasting impacts across sites suggests that there are a number of factors which can affect the level of blasting impact on a community. It is the particular constellation of these factors existing at a specific time and place rather than any single factor that determines the actual level of blasting impact on any specific community.

Specifically, the factors which appear to be most important for determining variation in levels of impact on community include:**

- 1) distance and density
- 2) quality of blasting practice by mines
- 3) fly-by-night firms
- 4) role of governmental regulation (Federal, state, local)
- 5) modus operandi: mine response to complaints
- 6) mine support of community
- 7) mining cultures: community infrastructure and norms
- 8) metropolitan centers
- 9) situation and person specific factors

E. Property Values

To examine the possible impact of blasting on property values, a study was made in urban residential areas adjacent to a selected sample of quarries representing differences in geographical location and size of

* The order of listing is not meant to imply relative priority or importance.

urban population. Quarries were selected because sites could be selected which would have a relatively high residential density and would have long term site operations, characteristics needed for property value analysis. The study was designed to control potential non-blasting causes of variation in market value of homes. Homes were classified according to type of home, dollar value, and interval distances from the quarry sites.

This study shows no consistent relationship between property value and distance from quarry sites.

Further data about possible blasting/property value relations was obtained during the field research through interviews with community members knowledgeable about local property values (specifically: lending institution officials, realtors, tax assessors, home insurance agents, homeowner associations).

For the most part, the perceptions and opinions of these local community members support the findings of the property value study that blasting and/or surface mining in general does not affect property values. However, there were some variations worth noting here.

Two variations are clearly related to surface mining per se rather than to blasting. First, property of local residents (whether residential or non-residential) may increase in value (sometimes significantly) when considered for mining purposes. In a word, a local resident's property may be more valuable for its mineral rights than for other uses.

Second, persons working in mines often seek residences in the vicinity of mines. The convenience of proximity to a job site is a positive aspect of property value for these persons.

A third variation, while apparently the exception rather than the rule, consisted of isolated instances where individuals did consider property value to be affected by proximity to mines, though the distinction between surface mining vs. blasting as the causal factor was not clear-cut in these instances.

A fourth variation from our basic findings may be significant. In two of the field study sites, homeowners strongly believe that blasting has negatively affected the value of their homes, and complaint levels are high. Both of these sites suggest that a particular constellation of site characteristics in metropolitan areas might, in contrast to our basic findings, make property values amenable to impact from blasting — though this conclusion is questionable and factual determination would be difficult because of other possible and plausible causes of property value variation in these sites.* However, regardless of factual determinations in these sites, mine-community relations are clearly aggravated by homeowner belief that impact has occurred.

* Factual determination of property value impact in these two sites was not possible within the scope of the field research, and would likely prove difficult if attempted.

III. IMPACTS OF REGULATIONS ON MINES

This study has found that current or future regulations can affect mine operations along four dimensions: efficiency of blasting practice; costs of blasting; industry infrastructure; small mines.

A. Efficiency of Blasting Practice

Prior to passage of PL 95-87, only a very few mines produced vibration levels at property boundaries above 2.0 in/sec, some above 1.0 in/sec and the majority were already below 0.5 in/sec. See Figure 2 on Page 284. The results of cost modeling of the drilling and blasting process (Figure 16 on page 310) show that cost increases required to meet various levels of restriction vary with the type of mine. Large area strip mines are virtually unaffected by restrictions as low as 0.25 in/sec. On the other hand, small contour strip mines in populated valleys face a 37% increase in drilling and blasting costs.

B. Drilling and Blasting Costs at Varying in/sec Levels

This study has found that currently available technology permits reduction from 2.0 in/sec to 1.0 in/sec without a significant increase in drilling and blasting costs, though there is some evidence that this may be less true for very small mines. However, below 1.0 in/sec, the cost curve for drilling and blasting increases sharply, though there is variation across types of mining methods and terrain.

To determine cost impacts to mines at varying in/sec levels and in different terrains, a permit sample was selected for each of the three basic terrains studied: steep, sloping and flat. Each sample was selected to be representative in size of permit area and housing density patterns for each of the three terrains. Since both of the latter factors will vary across permit areas, the estimates noted below are to be seen as reasonable average cost increases. Actual cost increases would, of course, vary around these projected averages.

The average cost increases for the sample permit areas in the three terrains are given below.

For contour stripping in the steep Appalachia area, a decrease of 0.5 in/sec (from 1.0 in/sec to 0.5 in/sec) results in a 12% drilling and blasting cost increase for a total permit area. A further reduction of only 0.25 in/sec (from 0.5 in/sec to 0.25 in/sec) results in an additional 10% cost increase.

For contour/area stripping methods in rolling hill terrain, the cost increase would be 37% for a reduction of 0.5 in/sec (from 1.0 to 0.5 in/sec) and an additional 21% cost increase for a further reduction of 0.25 in/sec (from 0.5 in/sec to 0.25 in/sec).

Interestingly, the area stripping in flat terrain case shows no significant cost increase—only 3% for a reduction of 1.75 in/sec (from 2.0 in/sec to 0.25 in/sec).

In order to understand the levels and variation of cost increases, it must be noted that these cost increases refer to an average cost for an entire permit area. For blasting at a permit boundary with structures nearby, the cost increase for a single blast would be much greater. However, the costs of these blasts must be combined with the cost of other more distant blasts which are not affected by in/sec regulations.

In this respect, the lack of significant cost increase for area stripping in flat terrain simply reflects the fact that permit areas in flat terrain regions tend to be quite large. Thus, a large percentage of the blasting occurs at sizeable distances away from any structure.

The cost increases noted above include only direct drilling and blasting costs, and even these may vary with differences in size of permit areas and in pay scales for drilling and blasting personnel. In addition, there are indirect costs for pre and/or post blast surveys, monitoring, use of consultants, general administration and paperwork. The exact amount of these indirect costs are accounted for in a variety of categories in mine company records and often are virtually impossible to identify precisely. Blast surveys were reported in a cost range of \$60-\$120 per home. Combined costs for monitoring and blast surveys were reported by mine owners to vary from month to month and to range from zero to \$100,000 (for blasting near small communities). Mine managers estimated that 5% to 10% of their time was required for regulation-related work (filing required forms, informing residents, etc.). Some mines reported the addition of a supervisory level position to handle matters related to blasting and blasting regulations (this seems to represent the upper level of management costs associated with blasting regulations).

C. Industry Infrastructure

Although this study was conducted too soon after the passage of PL 95-87 to draw definitive conclusions, there are indications that the blasting regulations are affecting the overall industry infrastructure in a number of ways. This should be further monitored and studied.

One change appears to be an increased use of consultants for such purposes as monitoring and blast surveys, designing blasts, record-keeping. In some cases mines were sub-contracting the entire drilling and blasting operation. In another instance, a large firm was sub-contracting to a small firm the entire mining operation for small permit areas.

Another change was noted earlier -- an increase in sophistication and efficiency of blasting methodology (e.g.: use of sequential timer integrated with delay blasting caps to increase the number of charges per delay which can be detonated; use of non-electric blasting technology).

A third change involves enhancement of the mine-distributor-manufacturer relationship. The use of distributors or manufacturers by mine companies as consultants regarding drilling and blasting methodology appears to be a potentially major mechanism for technology transfer to mines and is an area which should be studied intensively.*

There also appears to be a trend towards increased size of permit areas. In the rolling hill terrain where both contour and area stripping methods are used, it was noted that several mine companies are relying increasingly on area stripping of large permit areas. The primary reason appears to be that this permits use of draglines, which reduces both operating and reclamation costs. However, larger permit areas also allow average drilling and blasting costs for a permit area to be decreased.

D. Small Mines

There are indications that the small mine is particularly affected by PL 95-87 and would likely be even more strongly affected by further reduction in vibration levels.

As noted earlier, the cost increase for a reduction below 1.0 in/sec would be most significant in areas of steep and rolling hill terrain. These terrains (especially the steep Appalachian terrain) often do not permit the large scale area stripping methodology which is possible in flat terrain. Thus, these terrains more often have small mines which are less capable of absorbing the cost increases of lower vibration regulations.** Further, such an impact would affect a relatively high proportion of the total number of mines in the steep Appalachian region.

Another part of this report notes that size of mine per se is not a factor affecting the impact of blasting on community. However, size of mine does appear to affect the impact of reclamation and blasting regulation on mines. For example, mine operators, community leaders, and

* We are currently undertaking an initial study of this dynamic under contract with the National Science Foundation. While this mechanism for technology transfer has been in use for a long period of time, there is evidence that it is neither adequately understood nor utilized for maximum effectiveness and efficiency.

** The costs of reclamation and drilling/blasting must be considered cumulatively. Thus, while reclamation costs are a greater concern, additional significant increases in drilling/blasting costs could have major impact on small mines.

regulatory personnel expressed concern about the ability of small mines to remain viable. In some cases, these persons attributed recent closings of small mines to the cost impact of regulations.*

IV. IMPACT OF REGULATION ON MINE RESPONSE TO COMPLAINTS

Interviews with mines, community and regulatory personnel indicate that in many areas, there has been a modus operandi (tacit but well understood and agreed upon by both mines and communities) concerning relatively moderate cracking. Under this process, citizens would present their complaint of cracking impacts directly to the mine, and the mine would reimburse the citizen. This procedure has been followed by many mines (even where the cause of cracking is questionable) either to maintain community goodwill or to avoid more costly legal processes. However, since the passage of PL 95-87, there are indications that community residents are becoming more aware of their ability to make complaints, are making more complaints, and are increasing the amounts of compensation sought. In response, some mine operators indicated an unwillingness to continue with the modus operandi of previous years. Whether this represents a growing trend (and if so, with what implications) or is only a temporary phenomenon could not be determined at the time of this study and will thus need to be investigated further over the next several years.

V. DAMAGE CLASSIFICATIONS

A review of engineering, administrative and legal classifications or definitions of blast-induced damage was conducted both through review of relevant literature and interviews of persons involved in determining blast-related damage. This review reveals that there is no consensus about damage classifications, and that classifications used are vague and defined differently by different persons. While it appears unlikely that any comprehensive classification system would receive widespread acceptance, it is important that more accurate and less connotative descriptors be developed. We therefore recommend the following:

- 1) That the term cracking be used instead of the term damage. Cracking is a properly descriptive, non-connotative term. Damage is a value-laden term that implies a strong degree of severity.
- 2) That the severity of cracking be evaluated on three dimensions:
 - a) cosmetic cracking -- an aesthetic dimension
 - b) load loss -- an engineering dimension
 - c) cost of repair or replacement -- an economic dimension, applied to both cosmetic and load loss cracking.

* In areas with high sulphur coal, mine closings were sometimes attributed to EPA regulations eliminating spot markets for coal or preventing long term coal contract agreements for sale of coal to power generating facilities.

VI. ANNOYANCE FROM AIR BLASTS

One possible impact on community from surface mine blasting is annoyance. Since there are no studies of human annoyance in relation to surface blasting per se, an overview analysis was made of sonic boom studies and of studies of annoyance from vibration excitation and of human response to impulsive vibration.

Based on this analysis, a number of conclusions may be drawn:

- 1) People are far more annoyed by their house "rattling" than they are by the vibration they feel in the floor. This is true for both ground-borne vibration and air blasts.
- 2) Near a quarry or surface mine the magnitude of house vibration from a blast event is, on the average, the same from the ground vibration and the air blast at a scaled distance (ft/lbs^{1/2}) of 50. At greater scaled distances the air blast dominates and at smaller scaled distances the ground vibration dominates the house vibration. If the house is downwind of the blast the house vibration will always be dominated by the air blast (except if the house is located behind a quarry face).
- 3) A house exposed to a parting shot in a mining operation will always be shaken more by the air blast versus the ground vibration.
- 4) A house responds most to pressure pulses with a frequency between 3 and 25 Hz. Therefore, sound measurement systems should be capable of responding linearly to pressures in that frequency range.
- 5) A house wall facing the source of the air blast vibrates at a level three times greater than the house floor.
- 6) Blast noise or vibration cannot be related to annoyance on an energy basis such as L_{dn} used for aircraft, traffic, and other environmental noise. There appears to be a blast limit that people will tolerate and the number of blasts per day is of secondary importance. Indoor annoyance grows much more rapidly with increasing blast level than one would predict on a noise energy basis.

VII. CONDITIONS CONDUCIVE TO HIGH IMPACT

There appear to be some particular conditions which are especially conducive to high levels of blasting impact on community and which therefore warrant the special attention of policy makers. Four will be noted here. Two focus primarily on special community characteristics. The other two focus primarily on mine characteristics.

A. Confrontation Between Strangers: Expanding Non-Mining Communities vs. Expanding Mine Operations

Analysis of the high complaint level in Site No. 2* is very instructive. Here we find the following combination of context characteristics:

- * Site No. 2 is a major coal county producing more than 5,000,000 tons annually.**
- * Coal mining in the county adjacent to Site No. 2 is not a significant industry.
- * The adjacent county has a large metropolitan center, with suburbs in Site No. 2.
- * The specific areas in Site No. 2 where the complaint level is high is an expanding suburb of the metropolitan center in the adjacent county. The residents of this suburb are not connected with the mining industry either currently or in terms of background.
- * This suburb has been expanding in the direction of mine boundaries. Simultaneously, current mining operations have been moving in the direction of the suburb. Thus, in contrast to the time period in which most of the complaining residents built their homes, the mine now operates at distances 5000' and closer to the residential area. This has caught the residents by surprise. They hold local realtors responsible for not informing them of probable mining patterns in the area. At the same time, mine operators have been surprised by the level of complaints from the suburban residents.
- * From site observation and monitoring records, the conclusion would be reached that the mine company in question has a high quality of blasting practice.

In effect, then, Site No. 2 represents four conditions which seem highly conducive to a high level of community annoyance toward blasting:

- 1) A densely populated area (suburb of a metropolitan area).
- 2) Absence of a mining culture or orientation among residents, contrasted with mine companies that had historically operated in a county whose long term residents do have a mining orienta-

* As noted earlier, "site" refers here to a county chosen for the primary field research.

** Source: 1978 Keystone Coal Industry Manual.

tion — thus, residents and mines are "strangers" to each other.

- 3) An unstable context — a change from past conditions of distance between mine and community is created by the movement of mine and community boundaries directly towards each other.
- 4) The element of surprise or unexpectedness — residents did not anticipate close mining operations, and mines did not expect the response of the complaining residents.

While the conditions described above cannot be considered typical for coal producing regions, a simple map analysis suggests that the potential for similar situations does exist in certain areas. Somewhat similar conditions are associated with high complaint levels in Site No. 8 (major metropolitan area with quarrying as only one part of the total economic framework for the area) and also in a county adjacent to Site No. 5 (in the adjacent county, there is a major metropolitan area, and coal mining is one but not the only major industry in the adjacent county).*

Thus, such situations are important enough in terms of level of blasting impact and number of potential similar situations to suggest consideration by policy makers, but are not sufficiently widespread to suggest development of any policy applicable to all mining areas.

B. Site-Specific Factor Constellations Conducive to High Levels of Blasting Impacts

The above analysis of Site No. 2 suggests a particularly significant constellation of factors affecting blasting impact on community which have the potential for existing in several areas.

Analysis of Site No. 8 illustrates how a constellation of factors which is unique to a particular site may also be conducive to high levels of blasting impact, suggesting further the need for policy flexibility rather than developing broad, industry-wide policies on the basis of worst case conditions.

In this site severe complaints and a grassroots citizen's organization had appeared at a distance from quarrying operations that would normally be considered beyond that likely to result in cracking. Furthermore, there was relatively little evidence that vibration levels at the community site were above normally acceptable levels. Air-blast may also have been a factor.

* Eight sites (counties) were chosen for field research. In choosing these sites, a balance was sought between sites where complaint levels were likely to be high and sites where complaint levels were likely to be low. Thus, the percentage of study sites with high complaint levels is an artifact of analysis requirements and should not be interpreted to be a finding about the extensiveness of blasting impacts across all surface coal mining areas or counties.

Site No. 8 may well be one of those extremely unusual cases where a relatively anomolous geological structure, possible exasperated by dredging operations that had removed sand over a number of years from a cavernous sub-structure with a high water-table, combined with some potentially questionable construction practices (given the conditions, the recentness of the land development, etc.) resulted in patterns of vibration together with the air-blast effects, and consequent cracking, where it would normally not be expected.

Once again, it is difficult to distinguish between blast induced and settlement cracking, and any interaction effects between the two. Furthermore, again, the emergent nature of the problem and its unexpectedness for the residents together with a feeling of being politically and economically exploited contribute to a condition, which can then be seen to magnify when resident concerns seem to be dismissed out of hand as technically impossible. The manification can then take on political dimensions (as it did) to a point of resonance, resulting in the site being defined as a "hot spot". It is to be noted that our decision to study Site No. 8 was precisely because it had been identified as a "hot spot", and that it was not selected at random. It is our assessment that the conditions in Site No. 8 are quite atypical. Such situations must be dealt with as special cases and should not become a basis for setting general regulations.

C. Quality of Blasting Practice

As was noted earlier, the level of blasting impact on community is significantly determined by a mine's quality of blasting practice — i.e., the extent to which it can and does use current state-of-the-art methodology to control levels of i.p.s., dB and flyrock. This study found instances of both good and poor quality of blasting practice.

Because quality of blasting practice is important in all mining situations where structures are nearby, this is a basic area of policy concern. This study suggests, however, that quality of blasting practice is a multi-dimensional factor, and that policy response therefore needs to be designed accordingly.

One dimension, of course, concerns the levels of i.p.s. and dB which can be considered to provide an acceptable balance between protection of communities from blasting impacts and controlling cost of coal production (and thus cost of coal to consumers).

A second and obviously related dimension is the establishment and enforcement of regulations which specify acceptable levels of i.p.s. and dB which provide for monitoring and measuring actual blast levels.

This study suggests two other quite significant and interrelated dimensions of the issue: 1) the ability of mine companies/blasting personnel to use state-of-the-art methodology, and 2) the transfer of technology

(regarding both technology and technique) to mine companies and personnel. Here, the following may be important areas for policy concern and response:

- * The mining industry appears to be a loosely connected industry, a factor which would tend to hinder the transfer of technology.
- * The mine-distributor-manufacturer relationship appears to be a potentially valuable mechanism for transfer of technology, but the relationship varies across regions and across mines, distributors and manufacturers.
- * There are some indications that small mines may be less able than larger mines to upgrade their blasting competencies because of inadequate linkages to sources of technical assistance and/or because of costs involved for training and pay levels for highly trained personnel.
- * There are strong indications that many mining companies have minimal or inadequate cost accounting procedures and competencies. While this issue was not a primary focus of this study, difficulties were encountered during mine site visits in obtaining needed cost data.

The above suggest that policy responses to the issue of quality of blasting practices need to include consideration of training and technical assistance, and development of industry infrastructures and linkages for transfer of technology.

D. Fly-By-Night Firms

This study has also singled out the presence of fly-by-night firms as an aspect of the quality-of-practice and of the overall blasting impact issue of this study which is of sufficient importance to merit separate policy consideration. This was the one factor which was most consistently associated with strong blasting impacts by community members.

For purposes of policy consideration, several aspects of the fly-by-night dynamic need to be noted. First, the issue may not be so much the blasting competency of the firm but rather the firm's lack of concern about its impact on community.

Finally, one further distinction must be made as to types of fly-by-night firms. At one extreme would be those firms which lack any concern for the social impacts of their operation and which attempt to circumvent regulation. At the other (and more benign) extreme, would be firms consisting of one or more individuals who are not primarily in the mining business but who decide to mine a single plot of land (or perhaps periodically try their hand) at mining. In these latter cases, the issue may well be one of the blasting competency of the mine operators rather than a lack of social concern.

Second, the impact of fly-by-night firms on community transcends blasting impacts to also include damage to roads and property by trucks, lack of reclamation, etc. Thus, policy response to the issue of fly-by-night firms needs to have a broader perspective than just the impacts of blasting.

Third, interviewees in several sites noted that the operation of such firms are often difficult to detect and/or that control is hampered simply by the short term, in-and-out nature of these operations. On the other hand, interviewees in other sites noted that active enforcement of regulations and the use of such tactics as bond posting requirements for short term mining operations have been successful in minimizing the presence and impact of fly-by-night operations.

SECTION ONE

**THE SOCIAL IMPACTS
OF SURFACE MINE BLASTING**

Section One of this report presents an analysis of findings regarding the impacts of surface coal mine blasting on nearby local communities.

THE CONCEPT OF "IMPACT ON COMMUNITY"

A broad perspective on the issue is needed if for no other reason than that the concepts of "impact" and "community" are both quite multi-faceted.

This study has treated the concept of impact from three conceptually separate but pragmatically interactive dimensions.

- 1) The direct impacts of cracking and annoyance.

These are the impacts which may result directly from ground vibration, air blast and flyrock. However, while such impacts are conceptually clear, determination of actual cause-effect relationships is often problematic and inconclusive.

- 2) Community awareness of blasting as an issue.

Awareness refers to the extent to which there is a perception or belief among community residents that blasting is having an impact on their community, and the perceived kind and level of impact. Once again, this dimension of blasting impact is problematic in that "perception and belief" are to a significant degree "interpretations" and are often based on one's attitude and values.

- 3) Community response to blasting impact on community.

While response is obviously dependent on there being some degree of awareness of blasting as an issue, the kind and level of response may vary across individuals and communities and, further, are not necessarily predetermined either by a particular level of awareness or by the kind of impact perceived.

A fourth dimension of impact would be the "quality of life" impacts in such areas as: perceived desirability of a community as a place to live and work; property values (as an indicator); attractiveness to business and industry; tourism. However, this study has found that surface mining in general rather than blasting per se is the proper focus for any general analysis of quality of life impacts.

A distinction must also be noted between potential and actual blasting impact. The potential for blasting impact is determined by the demographic factors of distance and density (see Part Two) in relation to factors of terrain, geology, and levels of vibration, air blast and flyrock.

The concept of community also has several varying meanings which are relevant for this study. Thus, on the one hand, consideration must be

given to the impacts of blasting on individual members of a community. At the aggregate level, on the other hand, a community may range from a small cluster of nearby residents to towns and cities of varying sizes which may or may not overlap within a 5000' perimeter from a permit boundary. The relevant community may be those residents within range of direct impacts or more distance from blasting sites but subject to indirect impacts and/or affecting the response of residents to blasting. In this regard, this study has found that the presence of a large metropolitan area (core city of 100,000 or more) appears to affect community awareness and response.

In this report, the term impact on community is used to incorporate the above meanings of "impact" and "community" in order to simplify discussion.

ANALYZING IMPACT ON COMMUNITY

This study was designed to provide a broad perspective on the impact on community issue, and this is reflected both in the study design and the findings of the study.

A principle part of the study involved field research in a selected sample of counties. Criteria for selecting the counties for the sample were the following:

- 1) Mine-related criteria
 - a) Type of terrain
 - i) Flat
 - ii) Sloping (rolling hills)
 - iii) Steep
 - b) Type of mining method associated with type of terrain
 - i) Area stripping
 - ii) Area/contour stripping
 - iii) Contour stripping
 - c) Size of mine
 - i) Level of annual production
 - ii) Number and size of permit areas
 - d) Ownership and corporate structure
 - e) Number of mining firms
 - f) Coal market
 - g) Union/non-union

- 2) Community-related criteria
 - a) Density
 - i) County
 - ii) Towns/cities
 - iii) Within 5000' of current mine permit areas
 - iv) Population growth rate
 - b) Economic
 - i) Income levels
 - ii) Unemployment levels
 - iii) Type and mix of employment sources
 - iv) Degree of dependency of mining industry
 - c) Complaint level
 - d) Awareness of/response to blasting as an issue
 - e) State/local regulation

Data for site selection was obtained from a variety of sources, including: field observations and a one-day meeting of various knowledgeable informants during Phase One of the study; analysis of U.S.G.S. topographical maps; telephone interviews with regulatory, community and mine personnel; analysis of available printed materials (e.g., U.S. census reports; Keystone; maps; state and local publications).

Based on the above criteria and data, a sample of eight counties (each in different states) were selected to serve as the primary sites for the field research. These eight sites provide a representative, varied and balanced sample across the above criteria. Within each of these sites specific mine/community sets were selected for the intensive field research.

Project personnel spent approximately one person-week in each site collecting interview and other data from community residents and organizations,* including: county/city government personnel (mayors, commissioners, sheriffs, planning commissioners, engineers, tax assessors, school personnel); OSM and state regulatory personnel; local newspapers, Chambers of Commerce, realtors, insurance agents, lending organizations;

* Additionally, project personnel spent approximately 2½ person-days interviewing mine personnel and observing mine operations. These findings are reported primarily in Section Two, but complaint-related and mine/community interaction data collected during these interviews are incorporated into Section One of this report.

utility companies; local firms which do business with mines; local industries near mines; local community groups; individual residents living near mines and/or having made complaints about blasting.

During the field research at each site, data was obtained through unstructured interviews, observation and written materials (reports, records, publications, etc.) concerning such topics as: community awareness of blasting as an issue; nature, number and frequency of complaints; the complaint process (to whom and how are complaints made, under what conditions, etc.); patterns of mine/community relations and interactions; community demographic and sociological characteristics; property-related data (property value); direction and rate of new housing starts; impacts of blasting on buying/selling of property; loan/mortgage availability; insurance rates; description of structures near mines; use of damage classification systems and crack origination estimation techniques; local government awareness of and response to blasting as an issue (e.g.: use of laws, regulations, zoning, bonding requirements, permitting processes; formal filing of complaints or lawsuits).

OVERVIEW OF SECTION ONE

Section one is divided into seven Parts, as described below. Parts One and Three report the primary social findings of the field research, though as relevant field research data are incorporated into other Parts. The other Parts provide analyses of demographic patterns, lawsuits and formal complaints, property value impacts, classification of structural impacts, and annoyance.

Part One: A Constellation of Factors Affecting the Level of Blasting Impact on Community.

This study has found that the nature and level of impact on community (especially regarding community awareness of and response to blasting as an issue) is determined by the particular constellation of several key factors which exists in relation to a specific community and/or mine. Further, this study has found that impact on community is especially affected by: quality of blasting practice; fly-by-night firms; presence of a nearby metropolitan area (core city of 100,000 or more); and site-specific factor constellations.

Part Two: Demographic Analysis of Density Patterns Near Surface Coal Mines

To determine the potential for blasting impact on community, several analyses were made of density patterns in coal mining areas. These analyses include:

- 1) Density patterns around a sample of 101 current (1979) surface coal mine permit areas.

- 2) Density patterns of current mine permit areas using square mile sections.
- 3) Density patterns of towns/cities in and adjacent to surface mining counties.
- 4) Population per square mile in mining counties.

These analyses indicate a generally low pattern of density. For example, within 500' of the permit boundaries in the sample of current permit areas, there were no residential structures in 38.6 % of the cases and 7 or less in 89.1% of the cases. Between 500' and 1000' of permit boundaries there were no residential structures in 23.8 % of the cases and 11 or less in 89.1% of the cases. At the same time, there are instances (though relatively few) where density patterns are significantly higher.

Part Three: Analysis of Patterns of Formal Complaints and Legal Suits

Lawsuits and formal complaints to governmental regulatory agencies provide one set of indicators about issues and patterns of the impact of surface mine blasting.

It was recognized early in this study that a comprehensive legal and formal complaint analysis was not feasible. The absence of uniform reporting systems makes examination of staff trial level cases difficult. A similar lack of uniform reporting systems for complaints is found across state regulatory agencies -- and is compounded further by inadequacies in the data reported. Therefore, the legal and complaint research focused on state appellate and federal cases (using LEXIS as well as traditional legal research modes), state trial level cases in a sample of eight counties (in different states), and formal complaints in a sample of four counties (again in different states).

State appellate and federal cases appear to focus on three main issues of law: 1) strict liability vs. negligence; 2) measurement of appropriate amount of recovery; and 3) causation.

Analysis of state trial cases reveals a general lack of patterns in cases filed -- and also a relatively small number of cases. Trends and patterns were also difficult to discern in complaints to state regulatory agencies -- though here the inadequacies of available data base make analysis even more difficult.

Part Four: Analysis of Impacts on Property Values

A second indicator of blasting impact on community would be the affect of blasting on property values. An analysis was therefore made of property values around 7 quarries located in metropolitan areas at various locations in the eastern half of the United States. Quarries were selected because sites could be selected which would have a relatively high residential density and would have long term site operations, characteristics needed for property value analysis. The study was designed to control potential non-blasting causes of variation in market value of homes. Homes were classified according to type of home, dollar value, and interval distances from the quarry sites.

This study found no consistent relationship between the presence of a quarry and property values of residences around a quarry.

Part Five: Classification of Structural Impacts

A review of engineering, administrative and legal classifications or definitions of blast-induced damage was conducted both through review of relevant literature and interviews of persons involved in determining blast-related damage. This review reveals that there is no consensus about damage classifications, and that classifications used are vague and defined differently by different persons. While it appears unlikely that any comprehensive classification system would receive widespread acceptance, it is important that more accurate and less connotative descriptors be developed. We therefore recommend the following:

- 1) That the term cracking be used instead of the term damage. Cracking is a properly descriptive, non-connotative term. Damage is a value-laden term that implies a strong degree of severity.
- 2) That the severity of cracking be evaluated on three dimensions:
 - a) cosmetic cracking — an aesthetic dimension
 - b) load loss — an engineering dimension
 - c) cost of repair or replacement — an economic dimension, applied to both cosmetic and load loss cracking.

Part Six: Annoyance from Air Blasts

One possible impact from surface mine blasting is annoyance from air blasts and/or ground vibration. An analysis was therefore made of relevant studies regarding annoyance from sonic booms, human annoyance from vibration excitation, and human response to impulsive vibration. No study has been carried out directly relating surface blasting to annoyance. This analysis has concluded that

blast noise and ground vibration cannot be treated on an equal energy basis for trade-off between the number of blast events versus the magnitude of the blast. For example, reducing the number of blasts per day from 4 to 1 does not mean that that single blast intensity can be increased fourfold and expect the same annoyance produced by the 4 smaller blasts. Determination of the relationship between blast intensity, number of blasts and annoyance will require further controlled testing. The blast noise descriptor selected was C-weighted slow meter response as read from a precision sound level meter as this correlated with typical single family dwelling wall motion better than peak over pressure. There is no information available to tell whether C-weight slow response or CSEL correlates better with annoyance from blasting.

PART ONE

A CONSTELLATION OF FACTORS AFFECTING
THE LEVEL OF BLASTING IMPACT
ON COMMUNITY

AN OVERVIEW OF ISSUES AND FINDINGS

This study has found that the impact of blasting on community is determined not by a single factor but rather by the particular, interactive constellation of factors existing in a particular situation. Such factor constellations may vary across situations, and may serve either to increase or moderate blasting impact on community.

The term "impact on community" is used to reflect both

- 1) the various meanings of a community, ranging from an individual to a town, city or county, to a social grouping of people; and
- 2) an understanding of impact as a unitary concept having the dimensions of:
 - a) cracking and annoyance — i.e., the direct blasting impacts on community resulting from flyrock, vibration or airblast
 - b) community awareness of blasting as an issue
 - c) community response to blasting.

While these meanings of community and impact could be considered as separate issues or dynamics, they are so interactive that they must be considered together.

This study suggests that the following factors seem most likely to affect the nature and level of impact on community along the dimensions noted above:

- 1) distance and density
- 2) quality of blasting practice by mines
- 3) fly-by-night firms
- 4) role of governmental regulation (Federal, state, local)
- 5) modus operandi: mines response to complaints
- 6) mine support of community
- 7) mining cultures: community infrastructure and norms
- 8) metropolitan centers
- 9) situation and person specific factors

At the beginning of this study, numerous other factors were considered potentially important but were not found significant. For example, size of mine did not directly correlate with levels of community impact. The study did find that fly-by-night firms (which tend to be small) were clearly a major source of negative impacts. However, the dominant dynamic here was not size per se — many small firms have positive relations with and low impact on their communities. The presence or absence of mine unions was another factor for which consistent or direct correlations were not found.

Nevertheless, we believe that the thinking that gave rise to the original list of figures may be useful for other studies of this type and therefore we will reproduce that list as part of a methodological supplement to the site data synopsis which follows this overview of issues and findings.

I. DISTANCE AND DENSITY

Distance and density are two interactive factors which create a potential* for blasting impact on community.

Distance refers simply to the relative proximity (defined by some unit of measure such as number of feet) between a blasting site on the one hand and a man-made or natural structure on the other hand. Density refers to the number of such structures and/or people in a given area or location.

An increase in the distance between a blast site and a structure reduces the potential for cracking in the structure from vibration, air blast or flyrock from a blast (under specified conditions of charge weight, geological or atmospheric conditions, nature of the structure, and so on). A similar relation exists for potential annoyance impact, though here the relation is additionally complicated by such factors as whether a person is inside or outside a structure, differences among individuals in tolerance levels, whether a blast interrupts one's sleep, socio-cultural dynamics in a community, and so on. Density is in effect a multiplying factor for cracking and annoyance, by determining the number of structures or persons that could potentially be impacted by blasting.

Apart from the above technical aspects of the issue, the relationship between distance/density and impact on community becomes more complex and less linear, with impact being moderated by the total constellation of factors existing at a given site.

For example, a condition of low distance/high density increases the potential for cracking and annoyance. However, the extent to which these impacts on community actually occur would largely depend on the quality of blasting practice factor. Thus, under the low distance/high density condition, we found instances of both high and low cracking/annoyance impact.

Another dynamic moderating the distance/density factor is simply the choice of mining companies about where to blast. For example, the distance/density factor with respect to cracking/annoyance impact is reduced or eliminated when firms choose isolated mining sites; or choose not to blast in those sections of a permit area where distance/density would be a factor; or choose simply to buy any structures within close proximity of their permit area.

*The distinction is made between the "potential for" impact and actual impact. The extent to which impact could occur (potential) is limited by density/distance factors. The extent to which impact actually does occur will be affected by a variety of factors.

Still another factor to be considered is the size of the permit area. Where the permit area is quite large, much of the blasting would be distant from the permit boundary, thereby in effect negating the density factor around the permit boundary.*

The results of this study suggest that in relation to impact on community awareness of or response to blasting as an issue, distance and density are not primary causal factors. This was clearly illustrated in Site No. 7.** Here there was the interesting phenomenon of there being both road construction blasting on a hill directly overlooking a small town (low distance/high density) and surface mine blasting throughout the county (low density and usually moderate to high distance). Levels of vibration and air blast were clearly higher for the road construction than for the mine sites, yet citizens accepted annoyance impacts from the road construction blasting more readily than from surface mine blasting. Interviews at this site revealed a critical sociocultural dynamic: the road being built was seen as very important to the town. Thus, while annoyance impacts were relatively high, community response was low. In effect, the distance/density factor had been neutralized by sociocultural factors.

A somewhat different situation was found in Site No. 8. Here, citizen awareness and response was quite high. Damage to homes from blasting was claimed, complaints were numerous, and a citizen's group was quite active in the complaint process -- even though the blasting site was approximately three miles distant.

Sites Nos. 2 and 8 illustrate that density can be a contributing factor, both sites having large metropolitan areas and both having high complaint levels. However, as will be noted later, in both sites other factors seem to have been predominant.

* As is noted in Section Two, size of permit area is also critical in determining the cost to mines of variation in i.p.s. levels.

** As noted earlier, "site" is used to refer to a county. Eight counties were selected for the field research. Site No. 7, therefore, is one of these counties.

II: QUALITY OF BLASTING PRACTICE

To the extent that this study indicates the critical significance of any one factor concerning impact on community, the factor would be quality of blasting practice by mines. Quality of blasting practice refers to the extent to which a company has the competency and/or willingness to use state-of-the-art technology and methodology to control the levels of vibration and air blast and the extent and direction of flyrock -- thereby reducing cracking and annoyance impacts on community. Current blasting state-of-the-art is sufficient to enable blasters to meet current Federal blasting standards (or even to exceed them when necessary*) -- thereby preventing severe types of cracking or annoyance impacts.

The importance of quality of blasting practice can be seen from two perspectives: a) in terms of potential for impact on community; and b) in terms of the ability and/or willingness of mine companies to utilize state-of-the-art blasting technologies and techniques in ways to minimize impact on communities.

There is an obvious relation between quality of blasting practice and the potential for impact on community. As blasting is controlled in order to reduce flyrock and levels of vibration and air blast, cracking and annoyance impacts are lessened.** Thus, state-of-the-art techniques can be utilized, up to a point, to reduce cracking and annoyance impacts on community. This dynamic was observed during the field studies. For example, mines which have blasted at vibration levels below state or Federal standards often indicated they did so as a matter of maintaining good public relations, or in other instances, to avoid costs of damage claims and/or more costly lawsuits.*** Instances were also noted where community leaders associated lower complaint levels with the passage and active enforcement of state blasting regulations.

Conversely, a number of instances were found where impact on community could be associated with poor quality of blasting practice. This would seem most clearly to be the case where there is extreme flyrock damage, which tends to receive the most wide-spread publicity locally and/or beyond the local community. While such cases were found to be the exception, this can result from poor quality blasting practice, and the damage to the property and health of nearby residents can be quite significant. It is also noted that in some (but not all) of the sites having relatively high levels of complaints, improper blasting practices were observed (e.g.: improper stemming).

* Cost implications are discussed separately in Section Two.

** As noted earlier, the relation between blasting levels and annoyance can be affected by non-technical factors.

*** Some mines evidently blast at lower vibration levels simply to be "on the safe side" of compliance with regulations, whether the regulations specified the current 1.0 in/sec or the previous 2.0 in/sec. It is to be noted, however, that a lowering of vibration regulations below 1.0 in/sec would require a corresponding additional lowering of actual blasting levels for a company to maintain a "safe side" policy, with subsequent cost implications to the mines (see Section Two).

The potential for poor quality of blasting practice can be seen in the relative ease with which individuals may obtain permits to mine and obtain a rudimentary blasting capability. This potential is also evident in the variability of training, experience and observed practices noted during site visits to mines. However, instances were also noted where current Federal regulations (and to a lesser extent, state regulations) have had the effect of improving the quality of practice in a significant number of mines.

It is concluded that poor quality of blasting practice can lead to a high level of impact on community.* However, the reverse is not necessarily true -- i.e., a high level of community awareness and response to blasting does not necessarily indicate poor quality of blasting practice. For example, a high quality of blasting practice was noted at Site No. 2, yet this site had a very high level of community complaints. Relatedly, a number of interviewees suggested another dynamic -- the use of a complaint against blasting even where a mine was blasting properly in order to pressure a mine to acquiesce to some demand of the complainer (e.g.: simply to obtain money, or to get a relative employed by the mine). While such assertions are usually difficult to document, in some of the cases, monitoring records did reveal 0.5 in/sec levels or lower. In other cases, a high distance (in some cases greater than a mile) between blast site and the allegedly damaged structure appeared to support the assertion of a "false complaint", though we do recognize that damage could and in some unusual case can occur at such long distances.

* The discussion of quality of blasting practice requires further refinement concerning such matters as: what i.p.s. and dB levels have what levels of vibration or annoyance impacts; what impact levels are desirable and/or acceptable (and whether this may differ under different social or economic decisions); what costs would be involved. These issues are dealt with elsewhere in this study.

III. THE FLY-BY-NIGHT FACTOR

One of the strongest findings of this study is the extent to which community members, mine companies and regulatory officials associate both blasting and non-blasting related negative impacts on community to small fly-by-night mines. These are mine operations which are short term in nature and which lack either competency in blasting practice and/or concern for the impact of their blasting (or their other mine-related operations) on the community. In essence, such fly-by-night operations tend to operate outside of whatever norms or structures exist in the community for the control of blasting or other mine-related impacts on community, even in some instances to the extent of not obtaining mining permits.

These mines appear to be one of the causal factors associated with poor quality of practice and, therefore, subsequent high levels of community impact. For example, the worst case in Site No. 5 was described by community members in terms of "blowing off the side of the mountain". It is to be noted that in general Site No. 5 has a generally low complaint level, and this particular instance was a unique, one-of-a-kind occurrence in Site No. 5.* Nonetheless, the impact of flyrock from this blowout to a number of nearby homes was quite significant, and this case was a point of widespread community concern. The firm involved was described by community members as a fly-by-night operation.

The attribution of poor quality blasting practice and high levels of community impact to fly-by-night mining operations was generally consistent across the sites studied. In Site No. 2, bonding requirements had been established for the express purpose of controlling such firms.

Certain conditions seem to be more conducive than others for the appearance of fly-by-night firms. One important condition is lack of control through the permit process. In general, it appears to be relatively easy for anyone to obtain a permit to mine, and to obtain the rudimentary level of blasting capability needed to do blasting. Thus for example, one interviewee in Site No. 5 told of the local businessman who decided to mine the coal on a small parcel of land he owned. In Site No. 6, some firms completely avoided mining regulations. In this site, anyone obtaining a construction permit could remove up to 250 tons of coal as part of the "construction" process. Numerous instances were cited by interviewees of persons using this loop-hole to mine coal but avoid being regulated as a mine. By way of contrast, the use of bonding requirements for permits was reported by interviewees in Site No. 2 as having effectively reduced the problem of fly-by-night firms.

* As noted earlier, a "Site" in this discussion refers to a county selected as a site for field research. Since several mine companies and permit areas would be present in a county, both good and bad blasting practice may be found in any Site.

Geology would also seem to be a factor. Conditions of relatively shallow overburden with coal seams near the surface would seem to be more conducive to such small, short-term mining operations by persons having a minimum of equipment and blasting competency. Relatedly, remoteness of mining site and low, scattered density of community population would tend to permit fly-by-night firms to circumvent the permit and regulatory processes. While such conditions would minimize the number of homes/people which could be impacted, the related poor quality of blasting practice would tend to amplify the severity of blasting impacts to the (albeit few) nearby structures.

Four further points need to be made here.

First, fly-by-night firms tend to be quite small. However, size is not the relevant issue. The field studies found many small firms which had good quality of blasting practice and which were quite concerned with community impact issues. Competency and concern for community, not size, are the relevant factors.

Second, fly-by-night operations can be broadly distinguished into two types. On the one hand would be the case where the same person or company is involved over a relatively long period of time (one to several years) in a series of small, short term mining operations over a number of scattered mine sites. In these cases, concern for quick profits and lack of concern about community impact would increase the likelihood of impacts from poor quality of blasting practice. On the other hand, there are also one-time operations, i.e., individuals who own a parcel of land and decide to mine the coal on that land. Here, the issue of blasting competency would likely be critical.

Third, the impact of fly-by-night operations goes beyond the issue of blasting impact to environmental issues (lack of reclamation, flooding, etc.) and to issues of damage to property of community residents (e.g.: by trucks in order to access the mining site). While these are non-blasting related community impacts, they affect the community's response toward blasting. Indeed, these non-blasting related impacts of fly-by-night firms were noted more often by interviewees than were blasting related impacts.

Finally, determining the precise extent of the fly-by-night problem in terms of the number of such firms is likely to be difficult, and it was not within the scope of this study to do so. Nonetheless, the findings of this study suggest that this is a sufficiently extensive problem to warrant further examination by policy makers at both Federal and state levels.

IV. THE ROLE OF REGULATION

There are indications that the existence and active enforcement of Federal, state and/or local government regulations reduce the level of blasting impacts on community. This effect of regulation can be seen from a number of perspectives.

At the time of this study, OSM offices were just beginning to be developed. It was therefore not possible to study the effect of OSM as a regulatory agency on blasting practices and impacts. However, evidence was found that the 1.0 in/sec requirement of PL 95-87 has begun to affect the quality of blasting practice. Specifically, it was found that in order to reduce the added costs of meeting the 1.0 in/sec requirement, a number of mining firms were beginning to utilize more sophisticated drilling and blasting technologies and techniques, thus increasing their capability for high quality of blasting practice.*

Question could obviously be raised as to why such mines had not taken advantage of such cost reduction measures even in the absence of regulatory pressure. This study suggests that an inadequate understanding and use of cost accounting procedures within a sizeable portion of the industry may help answer this question. This is an area which needs further study.

During the site studies, instances were noted which suggest that state/local regulation can also have an important effect on the quality of blasting practice and on blasting impact on community. For example, in Site No. 3, interviewees suggested that state regulations and an active state regulatory agency were a major reason for low levels of complaints from citizens. By way of contrast, interviewees at several other sites noted a limited role of state regulation, attributed to: lack of state regulations; lack of active enforcement; disaggregation of responsibilities for various aspects of regulations across several state agencies; changes over time as to which state agency has responsibility for particular aspects of mine operations.

Another aspect of government regulation was noted in Site No. 2. Here a \$5000/acre bond is required. Three aspects of this are significant. First, the purpose of this bond is clearly to deter fly-by-night firms and is thus reduced to \$1000/acre after three years. It appears that this purpose has been well-served. The fly-by-night dynamic with its potential for impact on community through poor quality of mine blasting is noticeable by its absence in this site. The second aspect to be noted, however, is that Site No. 2 was a "hot spot" in terms of community awareness and response. Thus, Site No. 2 is a good illustration of

* Section Two discusses the cost-to-mine impact of reducing velocity 2.0 to 1.0 and below. We may note here that improvement in drilling/blasting techniques has permitted mines to minimize the cost impact of changing from 2.0 to 1.0 in/sec, but that this would not tend to be the case for blasting costs at levels below 1.0 in/sec.

the complexity of factors which lead to a low vs. high level of blasting impact on community. The third aspect to be noted is that the bond requirement is a reclamation rather than a blasting impact bond, yet it has the effect of minimizing one major cause of blasting impacts.

One aspect of the field site investigations was to examine local government initiatives for controlling blasting impacts on community. At least four basic local government mechanisms could be used for this purpose. However, with a few exceptions, little evidence was found of the use of these mechanisms.

One local government mechanism could be the use of planning and zoning regulations. Most of the local governments in the sites examined either did not have formal planning/zoning units or did not use zoning regulations with respect to blasting per se. This seems to be the result of two primary factors: (a) the location of mines generally away from centers of population; and (b) the size of the county in terms of population. Thus, as a general rule, less populated counties tended not to have or use zoning plans and regulations regarding blasting.

A second local government mechanism could be the process for granting permits for surface mining. For example, open hearings for mining permits could provide a potential mechanism for citizens to raise a challenge to mines in terms of the potential impacts of blasting. However, the use of this mechanism in relation to blasting per se seems minimal.

The use of bond requirements for permits (as in Site No. 2) could be a third local government mechanism for controlling blasting impacts on community. This was not found to be a prevalent practice.

A fourth local government mechanism could be the local police function. City police generally are not a factor, since most mining is outside of the city limits and thus beyond the jurisdiction of city police. County police units are therefore a more likely potential mechanism. However, the use of county police functions to impact mine blasting was found to be idiosyncratic, depending on the role perceptions of the county sheriff and not upon county government policy decisions. Thus for example, in Site No. 4 the county sheriff actively accepted the role of "complaint receiver", while in Site No. 5, the county sheriff clearly eschewed this role.

V. MODUS OPERANDI OF MINE RESPONSE TO COMPLAINTS

In many mining areas, there has developed a tacit but well understood and agreed upon modus operandi between mine and community concerning cracking complaints from citizens. Under this process, a citizen contacts the mine directly and the mine reimburses the citizen for the alleged blast-induced cracking. This process is followed regardless of whether blasting by the mine is a clear or questionable cause of the cracking.

The specific nature or form of the modus operandi varies across mines and communities. It may be a very informal process, or it may involve pre/post-blast surveys and other technical examinations. An insurance firm may or may not be part of the mine-citizen negotiation. The amount a mining company is willing to pay (or citizens to accept) may vary. Regardless of the specific form, the purpose from the mine's perspective is to maintain community goodwill and to avoid more costly legal processes. As a result of this process, the number of citizen complaints reaching the formal complaint or legal stage is minimized.

During the field site studies, indications were found that this modus operandi, though a long standing practice, may be changing. A number of mine operators commented that since the passage of PL 95-87, due to citizen awareness of the new laws and regulations they have seen an increase in both the number and the dollar amount of complaints. These mine operators indicated an increasing hesitancy about continuing to agree to settle such complaints informally, and several have already modified their procedures for handling citizens' complaints by increased utilization of technical consultants to determine causation, or by referring the complaint to the mine's insurance company.

It is also to be noted that a similar modus operandi sometimes exists between mine companies and local utilities, with regard specifically to blasting damage to power lines, etc.* This appears especially to be true in relation to electric utilities where the utility company is a customer of the mine. Thus, for example, in Site No. 5, several instances were found where power lines had been knocked down (though not usually by blasting), in one case disrupting service for two communities for several hours. Interestingly, none of the community leaders were even aware of such incidents, including an executive at the main office of the utility company. The modus operandi between the mine and utility companies was simply for the utility company to make repairs and for the mine company to pay the repair cost. Their relationship in these matters was quite clear and amicable, and such instances therefore were resolved locally and internally rather than publically.

* A few instances of damage to above ground power lines were found, but these were not prevalent, and in some of these instances the damage had occurred from a non-blast cause (e.g.: a pole hit by a loader).

VI. MINE SUPPORT OF COMMUNITY

An important aspect of the overall pattern of mine-community interaction is the way and extent to which mine companies provide support to their communities, beyond simply providing employment and taxes. The particular form of mine support of community can be broadly understood in terms of three basic types of support: 1) provision of functional service to the community-at-large or to individuals; 2) support for social aspects of community life; and 3) investment in the local community. No consistent distinctions were found between large and small mines as to type or extent (at least in a relative sense) of community support.

It was also found that the pattern of mine support of community had, in some instances, changed over time. In some cases this was reflected in a change in ownership or management personnel. This would seem especially true where the pattern of mine support of community in a county tended to reflect an individualistic, disaggregated variation across mines, in contrast to counties where there appeared to be a strong, common culture for mines to provide community support. In other cases, there were strong indications that mine companies have become more consciously concerned with mine-community relations over the past five to fifteen years. One interviewee stated: "The mines have been their own worst enemies, but they have been changing this in the past ten years."

The potential importance of mine support of community can be seen in terms of the development of mine-community communication and of community goodwill towards the mines, factors which can moderate community awareness of and response to blasting as an issue in the community.

Provision of Functional Services

A form of mine support of community found in many of the field research sites was the provision of services which helped meet functional needs of the community-at-large. Most often this would be the loan of mine equipment (though occasionally also personnel) for such usage as clearing of snow from the roads. In several sites, local government officials said they "only had to pick up the phone" to obtain such services from the mine companies.

While providing functional services to the community-at-large seemed the most prevalent, instances were also noted where mines provided functional services directly to individual residents. In one instance company equipment was used to deliver hay for farmers' livestock during conditions of extreme winter weather.

Support for Social Aspects of Community Life

Another quite prevalent form of mine support of community was for mine companies to support various aspects of a community's social life.

Most often this took the form of financial contributions for local schools or sports, charities, social service agencies, local colleges and technical schools, and so on. In some instances, quite sizeable contributions were noted (e.g.: major contributions for the building of a two million dollar community civic center-sports complex; providing funds to the local high school band for an overseas tour). In other instances, mine companies contributed funds for personal crises of community members (e.g.: flying a child with an eye disease to a distant medical center).

In addition to direct financial contributions, mine companies at times have aided in the construction of community facilities (most often, it seems, sports facilities or recreational parks). At other times, mine companies have donated (or sold) stripped land for such uses as development of recreational areas or the attraction of new industries to a community.

Investment in the Local Community

The extent to which mine companies support local economies by conducting their business in the local community appears to have a strong impact on community attitudes towards mines. Indeed, in most of the field sites there seemed to be an implicit but strong community expectation or norm that mines should reinvest in the local community. Interestingly, this norm includes not only the mine as a company which purchases supplies locally, but also mine owners and managers who live and shop in the local community. The presence of this norm was evidenced in both a positive and a negative sense. Community members were critical when they perceived a lack of such investment, and conversely, noted instances of investment with praise. These comments by interviewees, generally unsolicited, often had a tone of distinguishing between good mines which were concerned about the community and bad mines who were not concerned about the community.

VII. "MINING CULTURES": COMMUNITY SOCIOECONOMIC INFRASTRUCTURES AND NORMS

Observations across the various field research sites of this study suggest that under certain conditions, a community's socioeconomic infrastructure can lead to the development of a "mining culture" — i.e., a social culture and attendant norms supportive of mining activities in general. The presence of such a mining culture tends to moderate community awareness of and response to blasting as an issue.

Thus, one of the dynamics noted in several of the field research sites was a general willingness to live with non-extreme blasting impacts, and to apply social pressure on those who don't. For example, an interviewee in one field research site believed his home to have developed cracks from mine blasting, but commented, "I'm not going to do anything about it in this community." It is worthy of note that this person was relatively new to the community and did not have a personal background in mining, but was aware of and responsive to the general community norms concerning mines and mine blasting.

This study has identified a number of community infrastructure factors which can contribute to the development of a supportive mining culture. It is important to recognize that these factors are interrelated, that they are cumulative (both in interaction and in terms of development over time), and that they tend to lead to but do not guarantee the development of a supportive mining culture.

One factor is the economic importance of mining to a community relative to other industries as a source of employment and income. Thus, in one of the field research sites where mining is the predominant industry, an interviewee commented on the low complaint level with the simple explanation: "People here know that mining is the bread and butter of the community."

One illustration of the way in which the importance of mining to a community can moderate community response to blasting impacts was noted earlier. During interviews in Site No. 7, startle and rattle from loud air blasts were clearly observable from nearby road construction. However, interviewees stated that while they did not particularly like these blasting impacts, they were tolerating the impacts because of the importance of the road being built to their own businesses.

A special condition of high sulphur content in coal found in field research Sites Nos. 3 and 4 further illustrates how the economic importance of mining can affect community response. In both sites interviewees noted strong community antagonism towards EPA regulations which have led to mine closings and significant increases in community unemployment levels. On the other hand, in both sites it was also suggested that citizen perception of a declining coal industry has led to a higher level of complaints about blasting and other mining activities. The interpretation offered was simply that given a lessened probability of

long term economic importance of mining to the community, citizens were now more willing to seek short term gains from the mine companies.

A second, related factor is the extent to which mining permeates the social network of a community above and beyond consideration of employment per se. In one field research site, an interviewee commented: "Around here, it is difficult to find someone who is not either employed by the mines, related to someone who is, or is doing business with the mines." Such permeation of a community's social infrastructure would tend to magnify the actual economic importance of mining to a community, to increase the probability of norms developing which would be supportive of mining, and to provide the social mechanisms for enforcement of such norms.

A third factor to be considered is the extent to which the mining industry is indigenous to the community -- specifically, whether the mines are owned and/or operated by persons who are residents of the community. This factor was indirectly noted in the previous discussion of mine support of community. The points to be made here are simply that indigenous ownership/management of mines in a community can: a) facilitate problem-solving interaction and communication between mine management and community residents; b) provide the context for the community to exert social pressure on mine management to "act responsibly" (as defined by community norms); and c) lead to a sense of ownership or partnership by the community in relation to mines (contrasted to the dynamics associated with absentee landlords).

A fourth factor is the size of the community. Community can be seen as a cluster of residents, a town or city, a county, or some other socio-geographical area with size being defined in terms of number and/or density of population rather than geographical area. The infrastructure dynamic here is twofold. First, there are the strong, closely-knit social infrastructures typically associated with small town and country communities which establish and enforce community norms. Second, in smaller communities, the probabilities increase that mine personnel and community residents (and also, but perhaps to a lesser extent, regulatory personnel) interact with each other socially. It is relevant to note here that the highest levels of complaints found in this study were associated with areas having nearby large metropolitan centers.

A fifth factor is longevity of mine operations, of mine personnel and of community residents. A mining culture is most likely to develop where mining has been an important industry over a number of decades, where specific mine companies have been operating in the community for long periods of time (as contrasted with fly-by-night operations), where mine owners/managers are long term community residents, and where community residents have "grown up" in the community or some other mining community. The point here is that social cultures develop in a cumulative manner over time.

The findings of this study indicate that the presence of a mining culture tends to moderate community awareness of and response to blasting as an issue, and that the development and presence of a mining culture is affected by the aspects of a community's socio-economic infrastructure noted above.

It is important to recognize that as a social phenomenon, "mining culture" is a dynamic phenomenon. This perspective has several implications.

For example, since the particular combination of factors may vary from one community to another, the nature and extent of a mining culture may vary across communities, and for that matter, may differentially affect groups and individuals within a single community.

It must also be recognized that while the presence of a supportive mining culture may moderate community awareness and response regarding non-extreme blasting impacts, the same mining culture may not tolerate extreme blasting impacts, damage from blasting and other mine-related activities for fly-by-night firms, and other blasting or mine-related impacts and activities which are perceived as inconsistent with community norms for "responsible mine behavior". Such was found to be the case, for example, in Site No. 5. In this site, isolated blowouts from otherwise responsible firms were noted but not dwelled upon by interviewees. On the other hand, the same interviewees expressed strongly negative opinions towards one particular fly-by-night firm which blew off the side of the mountain. Similarly, in two other sites with highly supportive mining cultures, laws had been passed to restrict severely the operations of renegade fly-by-night firms.

The above discussion suggests that the attitude of mine management towards a community can either hinder or facilitate a supportive mining culture. This dynamic is implied in the previous discussion of mine support for community and is implied in the negative attitudes towards fly-by-night firms expressed by interviewees across the field research sites.

It is also to be recognized that as social phenomena, mining cultures can change over time and/or in response to particularly significant changes in the underlying context. For example, an interviewee in Site No. 5 stated: "The mines have been their own worst enemies, but they have been changing this in the past ten years". In this site, there was general agreement among interviewees that mine companies have become more consciously concerned with mine-community relations over the past five to fifteen years with an attendant strengthening of the local mining culture.

VIII. METROPOLITAN CENTERS

Analysis of the field research data of this study suggests the presence of a major metropolitan center (core city of 100,000 or more) near mining operations tends to augment the likelihood of community awareness of and response to blasting.

At the three field research sites where the highest levels of complaints were noted, the only characteristic common to all three sites was the presence of a major metropolitan center. Site No. 2 is a county which is itself not densely populated. However, it does contain a suburb of a major city in an adjacent county. Complaints centered around this suburb rather than in the rest of the county. Site No. 5 provides a supportive contrast. This county does not have a major metropolitan center, and complaint levels are low. In the adjacent county, there is a major metropolitan center, and complaint levels were reported higher. Site No. 8 is a metropolitan area and has quarries but no surface coal mining -- and a high level of complaints about alleged quarry blasting impacts.

Comparison of the characteristics of metropolitan and non-metropolitan areas suggests the correlation found in this study between high complaint levels and the presence of a major metropolitan center is not accidental. Simply put, metropolitan areas lack most of the factors suggested previously as being conducive to a supportive mining culture -- i.e., they are likely to have major industries other than coal mining; residents are less likely to be involved (directly or indirectly) in the mining industry (both currently and in terms of their background); there is likely to be less social interaction between mines and large portions of the community; etc. Thus, there is likely to be an absence of a mining culture to moderate community awareness of and response to blasting as an issue.

IX. SITUATION AND PERSON SPECIFIC FACTORS: THE UNUSUAL CONTEXT AND ISSUES OF MOTIVATION

The discussion in I-VIII above has suggested a set of factors which may be present in varying degrees in any surface coal mining area* and therefore should be considered with regard to general level policies. At the same time, this study has found blasting impact on community to be affected by situation and person factors which are specific to a particular situation.

For example, in one instance blasting impact on community appeared to be compounded by the presence of nearby active surface mining on three sides of a small town. Similarly, in another site, it was suggested that atypical underground water/geology patterns magnified the distance at which blast-induced ground vibration would travel, though this claim had not been substantiated at the time of the field research, and other social dynamics present at this site might account for strong community awareness and response. These would be illustrations of situation-specific factors which can compound (and at times confound) the issue of blasting impact on community — and while they may indeed be relevant to a specific situation, caution should be exercised in drawing generalized policy implications from such situations.

Blasting impact on community may also be affected by person specific factors — i.e., the specific nature or motives of the individual complainer. This person-specific dynamic has at least two major dimensions. On the one hand, is the issue of the chronic complainer. This is a complex issue, and it was not within the scope of this study to evaluate or judge whether or not individual persons are chronic complainers. Nonetheless, it is clear that in many instances, some complainants are perceived to be chronic complainers by mine personnel, various community leaders, and government agency personnel — and it would appear that in at least some instances, the appellation would be appropriate. In other instances, however, designating someone a chronic complainer appeared to be an effective (or at least convenient) way of ignoring potential issues.

Another dimension of the person-specific dynamic concerns the motivation of an individual complainant, specifically, the use of blasting impact as a means of obtaining some personal gain. For example, instances were reported by various interviewees of such motives as: trying to force a mine to employ a relative; threatening to build a trailer lot near a blasting site unless a mine agreed to a payoff demand; personal conflicts between a complainant and a mine owner; and so on. Again, it was not the purpose of this study to verify the veracity of such reports, but there were sufficient number and source variety of these reports to indicate that such events do occur.

* Major metropolitan centers are not common to surface coal mining areas, but neither is this condition unique. Further, quarries may often be located near metropolitan centers.

A SYNOPSIS OF SITE CHARACTERISTICS

Eight counties were selected as being a representative sample of surface coal mining and quarrying in the eastern half of the United States.* Field researchers spent an average of about 5 to 6 person days collecting social data** in each of these sites (counties). Additionally, about 2½-3 days were allotted to direct mine site technical research, where additional social data was collected.

The discussion which follows represents a descriptive synopsis of each of the eight basic field research sites. The actual data that were collected are far too voluminous to be reproduced in full in this report. Further, since the data were collected on a "promise of confidentiality" basis, reproducing them would not be appropriate. The synopses should however be sufficient to provide the reader with a general picture of the situations in the eight sites. To protect confidentiality, we have refrained from providing details as to the precise locations, output levels, etc. and have been deliberately vague about certain factual and descriptive details that could be used to identify the sites. With these caveats the descriptions do provide a relatively accurate picture of the eight situations.

*Criteria for site selection were noted earlier. One of the eight sites focused on quarries rather than coal mining.

** The initial list of data elements is provided at the end of this synopsis. These data elements were developed during Phase One of the study and field tested at the beginning of Phase Two. An earlier draft of this list was reviewed at a workshop of knowledgeable experts.

Synopsis of Site No. 1

Site No. 1 is characterized by flat land and strip mining. There is no current deep mining although there had been some in the past (and some land settlement still continues due to this). A relatively few strip sites produce about 10 million tons of coal per year, but production has been decreasing. This Midwestern county's population is significantly less than 50,000 and has shown only very slight growth since 1970. There are two moderate sized towns (under 10,000) and a few other quite small communities. Except for the two towns noted, population is generally sparse and scattered.

Mining is the predominant source of employment in the county, both directly and indirectly. In a small population county, this simple fact cannot help but affect the community infrastructure. As one community leader commented: "It's difficult not to have a connection, business or family, with some aspect of the county's leading employer". This interconnectedness has led to some charges of conflict of interest in relation to some county officials who had been mine employees or who do business with the mines.

While mining is the predominant industry in terms of the number of persons employed, the flat and rural nature of the county suggests agriculture as also a significant industry. Indeed, one county official flatly stated that "the choice in . . . county is whether to mine or farm." Thus, reclamation is a major concern. The mines are to have reclaimed the land to its original agricultural productivity potential within ten years, and they appear to be following through this commitment. The mining industry was characterized as being "a friendly giant."

There are differing opinions within the county about the mines in general and about blasting in particular. The level of complaints would not lead to a clear characterization of the county as a "hot spot," and coal companies state that pre-blast surveys are provided, that all shots are monitored, and that shots fall well within the 1.0 in/sec regulation. Their monitoring records appear to confirm this. Coal companies also assert that sizeable reserves are being lost due to blasting regulations.

Yet there are complaints. One citizen claimed that a company was filling up their creek as well as endangering their house by blasting. They claimed instances of fly-rock in the yard and movement in their foundation. The company contended that the house was settling. This citizen relied only on calling the company to complain, unaware of any formal complaint mechanisms. There is an active community organization (though this is a regional rather than a local organization) which has been engaged as a consultant by the county commissioners (a fact of which they are very proud). A local paper carried articles on coal mining and blasting close to dwellings. As a result of the articles, some blasting operations were stopped.

There have been several suits filed alleging blasting damage. The mining companies took the position that the damage was not due to

blasting. These cases have been settled out of court. It was said that homeowners were reluctant to engage expert witnesses.

It is not clear what direction the level of complaints is likely to take. Some knowledgeable residents believed that with an active newspaper and an active regional community organization, the level of complaints will increase as residents become more aware of the issues and of complaint mechanisms. Other knowledgeable residents made the observation that there is a sense in the community that the mines may be "pulling out" (due at least in part to the high sulphur content of the coal) and that residents may now be willing "to get what they can from the mines while they can." On the other hand, other community leaders were of the opinion that the mine companies have been becoming more aware of the importance of maintaining good community ties and that as a result the number of complaints has been declining.

One particular area where complaints have been made is worth special note. One small, village-type community has mines being opened on three sides of the community.

Synopsis of Site No. 2

Site No. 2, which is located in a Midwestern state, is characterized by flat terrain and strip mining by large coal companies. The county has a total population of under 50,000 and has several towns in the 1,000 - 10,000 population range. While the county's population is not large, it has two very important characteristics. First, the county borders a major metropolitan area (100,000 or more population of a core city). Second, the county's population increased more than 30% between 1970 and 1978—to a large extent as a result of people who work in the adjacent metropolitan center building residences (of a "bedroom community" type) in Site No. 2.

Mining is the predominant industry in the county, and several large companies are present. The mining industry is well established, and there have developed close working relations between the mining companies and local/county government agencies. Indeed, it is worthy of note that in 1978 the county exempted the mining removal and transportation of coal from zoning regulations—including a section relating to "nuisances." Government officials maintain that the mining companies are civic minded and do their best to ensure good relations with the community.

Two aspects of Site No. 2 deserve special attention. One is the "metropolitan dynamic." The other is the use of regulation to control "fly-by-night" firms.

The "metropolitan dynamics" (also noted in Sites Nos. 5 and 8) is critical to understanding surface mine blasting as an issue in Site No. 2. Thus, on the one hand, there is a long-standing coal mining industry, which has resulted in the development of a "mining culture" within the largest

(geographically) portion of the county. For that part of the county, there is no significant level of complaints, and blasting does not seem to be much of an issue.

Yet Site No. 2 is clearly a "hot spot"—or more correctly that portion of the county adjacent to the metropolitan center is a "hot spot." Three interactive dynamics perhaps best explain the development of this area as a "hot spot."

- 1) Residence dwellings tend to be new and are typically in the \$40/100,000 range.
- 2) The residents have no current or historical ties to the mining industry. Thus they have no personal interest in, commitment to or understanding of the mining industry. There simply exists no fabric of a mining culture or infrastructure providing norms and values to provide a basis for communication and for "internal"/"local" problem solving. This dynamic also tends to hold true for the mine companies in relation to this community.
- 3) The mines and the community have been moving geographically towards each other—the mines moving their stripping operations towards the community and the town building in the direction of the mines.

The result can probably best be characterized as the surprised meeting of strangers—and strangers whose primary concerns tend to be in conflict. Indeed, many of the community's residents blame the local realtors for not informing them about the potential "mining problem." For their part, the mines have been caught by surprise by all the complaints. After all, they had in previous years operated the same way without such problems—but in the context of a mining culture. It is further worth noting that this "meeting of strangers" has not only made communication difficult, it has also resulted in a high level of distrust. Both the mine companies and the local community action group were quite hesitant about being interviewed by the field researchers of this project—both were rather concerned that the researchers might really be "sent by the other side." Thus, there appears to have developed an escalating and self-sustaining cycle— inability to communicate leads to distrust leads to greater inability to communicate, etc.

It is also to be noted that the high level of complaints cannot be attributed to poor quality of blasting practice. To the contrary, both visual on-site observation and examination of monitoring records indicate a high degree of professionalism in blasting practice and levels of vibration within or well below the 1.0 in/sec regulation. The local OSM office further confirms that the blasting is in accordance with regulatory limits.

The second major aspect of Site No. 2 which must be noted is the use of bonding to minimize problems with fly-by-night firms—for despite its characterization as a "hot spot," it is not characterized by irresponsi-

ble small firms. Specifically, a \$5000/acre bond is required in order to obtain a surface mining permit. After 3 years, the bond is reduced to \$1000/acre. Clearly, the bond is designed to discourage "short and quick" operations—the kind most likely to be either incompetent or unconcerned with regard to blasting and blasting impacts. Interestingly, the bond is a reclamation rather than a blasting bond.

Synopsis of Site No. 3

Site No. 3 is an Eastern county characterized by rolling hill terrain. The county's population, which is in the 50/100,000 range, has grown about 10% since 1970. About three-fourths of the county's population live in rural areas. There are several small towns scattered throughout the county—most under 5,000 population and only one greater than 10,000 population.

Realtors indicate that the average house value would be in the \$10/50,000 range, but that houses up to the mid-\$100,000 range would not be too exceptional. Between two-thirds and three-fourths of the homes are owner occupied. Unemployment has generally been low though it has recently increased a few percentage points. Local residents generally attribute this to the effect of government regulations on the coal mining industry—and many citizens express dislike of the way such regulations affect their "bread and butter."

Mining is the primary industry, both currently and historically. There is, however, a modest mix of other industries—light manufacturing, agriculture, forestry—and there is some indication of a modest trend towards diversification.

There appears to be a dynamic, highly interactive and positively perceived mining culture in the county. Most mine owners are lifetime county residents, and they are active politically and financially in the county. Residents noted such examples of mine involvement in the community as helping the local band take an overseas trip or donating land for a recreational park. Residents generally speak well of mine companies, both large and small.

State regulations in this state are tight and systematic, with an active inspection system. Regulatory officials, local government officials and community members all consider the "fly-by-night" type of firm to be the source of any real problems with the mining industry—and the regulatory process appears to have minimized this problem.

The mining industry itself appears to be highly professional, especially in the area of blasting. For example, the largest contract blaster in the area (serving several dozen mine companies) sends its blasters (including the owner) to classes for training every few months at the expense of the contract blasting firm. For another example, of some 40 to 50 inspections performed by a federal agency, no violations were issued either for blasting or for failure to maintain proper records.

The impact of blasting on the community does not appear to be a major issue in Site No. 3. Local papers have had no lead stories or stories in the community news section concerning blasting problems—even reporters and the editors were not aware of any significant problems. If there is a "main concern," it is with water wells—but this seems to be a long-standing problem in this county, and it is difficult if not impossible to determine the cause of deterioration and drying up of well water.

However, the mining culture modus operandi comes into play here. Most companies (but especially the larger ones which can more easily afford it) will drill new wells if there is any question at all as to the cause of a "well problem." There was one instance where blasting evidently did cause window breakage in a nearby school, but these were repaired by the mine company and there was no indication of ill will or of concern (by residents or school personnel) about the overall impact of blasting on the school. As the local school superintendent put it: "We just had the windows fixed, and that was that." Realtors indicate no impact of blasting on property values of dwellings either near or far from surface mine sites—and it is to be noted that most (though not all) mines are in remote and sparsely populated areas. As in other sites, road damage was more of a concern than blasting impacts.

Actual complaints are few. For the most part, complaints would be handled directly between the resident and the mine. Otherwise, most complaints ("several per year") are made to the state agency or to the local government—only one has gone to the federal level and one or two a year are made to a local mining supply company.

Synopsis of Site No. 4

Site No. 4 is characterized by rolling hill terrain. The Midwestern county's population is in the 50/100,000 range. Most but not all of the dozen or so towns in the county are in the 1,000 to 10,000 range. Approximately 1/4 to 1/3 of the county's population is located in and around one city. According to local officials, there is a trend towards redistribution of the population away from this city into rural areas. Visual observation of the city would seem to support this assertion—the many old, vacant buildings stand in sharp contrast to the general absence of newer building.

The county population as whole has declined by several thousand during the 1970's, at a rate of about 3% annually. According to local officials, the decline reflects the leaving of the young and the educated.

This site is one of the highest coal producing counties in the state. It is part of a larger mining area which spans three states, and has a long-term history of mining. However, while the mining industry is perceived as important to the economy of the county, it is only one of three major industries and is not the largest industry. Further, the coal industry

has been in a period of decline because of the high sulphur content of the coal. Several mines have closed in the past few years. Indeed, a number of local residents interviewed indicated their disapproval of EPA regulations because of the effect on the mining industry.

The relationship of the mine companies to the community can best be characterized overall as supportive but not highly interactive, though the relationship varies across mines. The general pattern is for mines to provide support for community in such matters as: education, sports and entertainment; snow removal; delivering hay to farmers in periods of heavy snow; and the like. However, personal involvement of mine owners seems to be less both in terms of leadership and in such matters as not investing within the county. How a mine company interacts with the community appears to be an individualistic matter--i.e., depending on and varying across specific mine owners/operators.

For the most part, blasting does not seem to be a major issue in Site No. 4. There are several community groups in the county, yet none has been concerned about blasting. Over the past several years the county newspaper has not published an article or editorial concerning blasting; and the one letter to the editor which did appear in the past five years related to road construction rather than surface mine blasting. Local officials identified damage to roads by coal trucks as their concern rather than blasting.

The county does have a complaint process which is idiosyncratic to the county. Specifically, the county sheriff has accepted the role of "complaint taker"--he has received 32 complaint calls (eight from one resident) in the past 18 months. These are published in the county newspaper in a minor column of community events and advertisements--more in the tone of a curiosity item than a significant news event.

Residents are generally unaware of any other formal complaint mechanism. The kind of mine/community modus operandi for cases of alleged blasting impact was not generally mentioned. This is consistent with the individualistic nature of mine/community relations noted previously.

Site No. 4, then, represents a "mixed case" situation. On the one hand, mining is currently and historically important to the community, residents are generally supportive of the mining industry, and there is a "mining culture." On the other hand, mining is not the sole or even the largest economic base for the county, and mine/community relations are individualistic and tend to be indirect.

Synopsis of Site No. 5

Site No. 5 is a Southern county characterized by rolling hill terrain. The population of the county is in the 50-100,000 range. It has only one town of greater than 10,000 population and several smaller towns scattered throughout the county. The largest town, which is the county seat, has a generally neat appearance and several newer homes and other

buildings. The outlying towns are generally quite small, and homes may range from older, smaller, and somewhat run-down buildings to older, well kept and newer homes. In these towns, the commercial section typically consists of a few businesses on or adjacent to the highway.

Site No. 5 is a high coal producing county, with an output of over 5,000,000 tons per annum. Both large and small mining companies may be found here. Indeed, at least one case was found where a larger firm subcontracted to a smaller firm the entire operations of one of the larger firms' mine sites.

Employment in Site No. 5 is strongly but not completely related to the mining industry. Within the county there is some light manufacturing; and some residents do commute to a major metropolitan area in an adjacent county. Nonetheless, mining is the predominant industry both currently and historically.

The importance of coal mining to the county can easily be seen in a historical purview of the county population. As related by one local community leader, county population was at a peak in the 1940's when both the railroads and the power company relied on coal as a fuel. In the 1950's, however, both switched to diesel as a primary fuel, with a resulting loss of coal mining employment. During the 1950's and 1960's, the county dropped heavily in population, the loss evidently consisting in large part of young workers and their families. With the energy crisis of the 1970's, coal production has increased and the county had a population increase between 1970 and 1978 almost equalling its previous loss.

The social impact of the importance of coal mining in Site No. 5 can be seen in other ways as well. For example, there clearly is a general modus operandi for dealing with blasting related complaints. Formal complaint levels to federal and state regulatory agencies are quite low, there is no active community group complaining against blasting, and various local officials and agencies report few complaints. Rather, citizens tend to deal directly with mine companies. One company (which keeps a record of complaints) averaged one call per month for 1978, and each incident was followed up by personal contact with the homeowner. This mine estimates it will pay an average of \$2500 annually and considers this to be "good will." It may also be noted that this modus operandi operates between mining companies and public utilities. Even here, problems are settled at the local level. In one instance, local community leaders (and even officials at the main office of the power company) were not even aware of a main power line being knocked down (by a loader, not by blasting). The local power company representative had simply called in repair crews and billed the mine company for damages—which were paid without questioning. Both sides clearly understood the modus operandi for handling problems at the local level.

Community leaders generally characterize mining companies as being responsible and responsive—though some noted this had not always been the case. This is not to say that there were no problems. Indeed there had been one incident of poor blasting, characterized by one citizen as

"fleecing of the side of the mountain." However, incidents such as these (which were not numerous) were clearly perceived by local residents to be caused by small fly-by-night firms. Most mines, large and small, are perceived as responsible. (Monitoring data recording blast levels of 0.05, 0.03 and 0.01 in/sec would seem to substantiate their perceptions.)

Site No. 5 may be characterized, then, as a moderate to sparsely populated area with a historically developed and active mining culture. This mining culture and high quality blasting practices by mines serve to moderate the potential and actual social impacts of blasting in this county--except in the case of fly-by-night firms. It is worthy of note that blasting-related complaints were reported to be much higher in an adjacent county--a county having a major metropolitan center and where mining is an important but not a dominant industry.

Synopsis of Site No. 6

Located in Appalachia, the county is a well-established, hilly, bituminous coal region with both strip and deep mining, each type producing about one and one half million tons of coal per year. The approximately 30 strip mine sites are all quite small, with several under 10,000 tons per year. There are two larger mines in operation, and several much larger ones under development. One local company owns a half dozen sites in the county (including several of the larger sites), and another 6 or 7 companies own 2 or 3 sites each. One of these companies reaches almost 300,000 tons; the rest are very small. Most of the rest of the sites are owned by medium sized companies from outside the county. The mines are non-union.

The community consists of a small county seat of under 5,000 population. The total population of the county is sparse, under 30,000, and 60% of employment is somehow related with the coal industry. A miner averages \$15,000 - 20,000/year. Relatively, the county, itself, is in a low economic state; roads and schools are poor; tax rates are very low. An average home in the county costs about \$35,000. Property values have risen. The coal companies play a fairly active financial role in supporting community projects - park and recreation, swimming-pool, tennis, the volunteer fire department, etc. The county seat has a very rudimentary governmental structure, no city planning or engineer, etc. They don't want or seek Federal help - "foreigners" (i.e. people from outside the county) and even their funds are looked upon with suspicion.

For the most part there are very few complaints concerning the mining in general or regarding blasting in particular. There is something of an issue with respect to subsidence because of the deep mining in the area. The mines publish their blasting schedule in a local newspaper. By and large the mines are considered very responsible. They were said not to have "caused problems." There is no evidence of property values being depressed by proximity to strip mines.

However, there have been a few complaints and suits brought against mines for damage said to have been caused by blasting. Two relatively similar cases went to jury trial, but resulted in opposite verdicts. In the case that was found for the plaintiff against the largest of the mining companies in the county, the homeowner claimed \$30,000 for cracking to his porch and other annoyances and was awarded \$15,000. The case was being appealed. The plaintiff's case was based solely on his own testimony and that of friends and neighbors. The mine brought in "expert witnesses" on blasting and vibration, cited the "impossibility of damage at the low levels of vibration involved" and the fact that there had been no damage to his sidewalk, and that a home much closer to the blast had not been damaged. The fact that the owner was handicapped and was "wheeled into court in his chair" was mentioned as an influencing factor. In the case that had been lost, the plaintiff had sued for \$20,000 for damage to a house of assessed value of \$29,000.

In a third case a fairly large award was made to the owner of a rather modest house (almost equal to 80% of the \$26,000 value of the house) to repair cracks. They had claimed \$35,000 for numerous cracks and annoyance. A local realtor estimated that \$5,000 would be required to do the work. Originally, (he stated) the homeowners would have settled for \$8,000, but the insurance company had refused to settle. The mine had claimed that since the house was located at almost 4,200 feet from the blast site and that since seismograph readings were well within regulatory limits (under 0.5 in/sec), it could not have been due to them; in any case, a structure located at 2100 feet had not been damaged. It was the mine's contention that the damage had been due to weather. The homeowner had brought in a local professor as an expert witness. The award was made at a second trial - the first had ended with a hung jury.

In a fourth case a mobile home owner, located 3,300 feet from the blast zone, had sued for \$30,000 and received \$3,000. Apart from these cases, complaints were not common.

It was a widespread feeling that these suits represented deviant situations - of people with no real stake in the community using the mines to obtain extra money to "fix up their homes, take vacations," etc. The local banker and the realtors took the position that the complaints were highly exaggerated and/or fundamentally not valid; but it was our sense that these people also had a vested interest in this position. However, discussions with other citizens, law enforcement people, newspaper people, etc. also indicated that blasting had really caused few problems and that the mines tried to be good citizens. It was our own assessment that the level of expertise regarding blasting effects was not extensive in this area.

For the most part, Site No. 6 represents an area where there is a mining culture and where for the most part blasting effects were a non-event. However, as is illustrated in this case, even in such a community individual citizens who may not be fully integrated into the social system and who happen to live within some proximity of blasting may act deviantly

from the local social norm, whether legitimately or not. Under these conditions and given generally a low level of understanding of the possible consequences of blasting among citizens, local officials, the courts, etc., a few suites can emerge and a few awards won against the mines (others lost) but in a near random manner. That the few complaints had escalated into suits seemed partly a result of breakdown in relations between the mines and certain non-local people (foreigners as they would view it) and the commensurate feelings on the part of these homeowners that, either, this was the only way they could obtain redress and/or a desire to exploit the opportunity that blasting (and current concerns over it) presented.

Synopsis of Site No. 7

Site No. 7, located in the Appalachians, is characterized by steep, mountainous terrain and is sparsely populated. The total population of the county is significantly under 50,000. Homes are generally scattered throughout the county with an occasional clustering of a small number of homes. There are only a few towns, each quite small. However, there is a technical school and a fairly new local community college in the largest of these towns. Mine permit areas generally are in remote, isolated areas. A large portion of the county is unsuitable for agricultural cultivation, though the valleys are quite fertile. During the frequent heavy rains, flooding often occurs.

The economy of the county is strongly dependent on coal mining. The mining industry is the largest single source of employment. There are some modest indicators of growth in service industries. Mining has shown a pattern of slow growth. The county ranks in the mid-upper range of coal and surface coal production levels among counties in this state. There is some concern that sulphur content restrictions could affect the mining industry in this area. Interviews clearly indicated community perception of mining as a "bread and butter" industry. A comment made by several community leaders was that as coal sales go up, so do other sales (and vice versa).

For the most part, mine companies have been in the county for a long time. New mines are being opened, but usually by existing companies. However, instances of fly-by-night types of operations are also found. Often these operations take advantage of a county regulation allowing removal of up to 250 tons of coal without a mining permit if a permit is obtained for road construction, land improvement, etc. However, instances were noted where even the latter types of permit were not obtained.

There is some evidence of rising property values resulting from the desire of miners to have homes near newly opened mines.

Given the economic dependence on mining, the long-term nature of the mining industry in the county, and the general sparsity of population, it could reasonably be expected that there would be a well developed mining culture with few real mine/community problems. This appears not to be the case-- there are complaints. There is a highly active community action organization which reports that it receives strip mining complaints "constantly."

(Residents appear to respect the ideals and motivation of this organization, but also seems to feel it sometimes "gets out of hand.") Several knowledgeable local leaders expect that complaints (including blasting complaints) will increase as residents become more aware of the channels open to them at the county, state and federal levels.

Two aspects of the apparent lack of good mine/community relations need to be noted: the nature of the complaints and the dynamics underlying the lack of positive mine/community relations.

As for the nature of the complaints, it is to be noted that while there are blasting-related complaints, they appear to be a minority. The issue is not so much blasting as it is strip mining per se (and mining in general). For example, complaints in the files of a state regulatory agency show a range of issues, such as: muddy water in a creek (state inspector found it to be due to heavy rains); tearing up roads; no permit sign posted; hauling coal over private property (state inspector found the road to be a county road); coal and mud slides blocking road; stripping without permit (permit had been obtained); plugged culvert, flooding possible; slide into yard (\$1,000 fine); unsafe silt dam (company agreed to pump it out); water from silt dam; excess water; land not reclaimed; mud and dust on highway (there was, but was from construction, not mining); water in garage.

Several basic observations may be drawn from the above sample of complaints (which is quite representative). First, water and road/property damage issues tend to predominate. Second, blasting does not predominate. Third, there appears to be poor mine/community interaction—an observation generally confirmed in interviews.

The issue, then, is not blasting, but a more generalized breakdown of mine/community relations. What, then, is the underlying dynamic leading to such a breakdown? There appears to be no single predominant factor but rather an overwhelming convergence of multiple factors. For example:

- 1) Overall, the county must be considered a "poor" county. According to HUD figures, 25.1 percent of the population was below the poverty line in 1978—though even this represents a slight decline from 29.2 percent in 1975.
- 2) There appears to be little positive interaction between mines and the community. Such simple indicators as mines sponsoring sports teams were notable by their absence. Community leaders often commented that mine companies and owners "spend their money elsewhere."
- 3) In earlier times, all mining was underground. Many such mines are now abandoned but have left problems of carcinogenic and mutagenic coal liquids for which strip mines may be blamed.
- 4) Given the quite steep terrain, small (and often short-term) mines predominate. This leads to problems of low wages,

inadequate training, and fly-by-night operations. There is, however, a current trend towards larger mines.

- 5) The problem of fly-by-night operations is magnified by a county regulation which allows removal of up to 250 tons of coal with a construction permit—thereby allowing many small operators to bypass the more stringent surface mine permitting process. Further, there are indications that some mine operations bypass even the construction permitting process.
- 6) There is division and resulting confusion of regulatory responsibility across (and even within) federal, state and local levels. Further, regulatory officials see themselves as being severely understaffed.
- 7) Water problems (wells, flooding, etc.) are seen as major, but have multiple possible causes, with actual often being difficult to determine. Knowledgeable persons in the community noted, as one example, that flooding has been a problem long before particular mines were open, yet they also noted that it is often difficult to convince other residents that the mines may not be at fault.
- 8) A unique factor is the existence of Broad Form Deeds, signed by property owners many decades ago, which gave away mineral rights. These were signed at a time when the land owners evidently were not aware of the potential value of their land for mining.
- 9) Road construction blasting often appears to be confused with strip mine blasting.

Site No. 7, then, is a "mixed evidence" site. There is a moderately high level of complaints, but the complaints are not primarily about blasting; knowledgeable local resource persons gave sometimes contradictory projections as to whether the complaint level is increasing or decreasing (one insurance company noted that the number of claims had been decreasing over the past six years, and that most settlements have been for less than \$500); there is community awareness of mining as a "bread and butter" industry.

It may also be noted that local residents were upset with what appeared to them to be "nonsensical" regulations—specifically, the reclamation requirement for restoring the original steep contours after mountaintop removal. Residents wanted the flat land for building purposes.

Issues related to surface mining are still being delineated in Site No. 7. They do not seem to admit to a simplistic regulatory approach—though both general mining and blasting-specific regulations and regulatory processes could potentially make a contribution towards the lessening of problems.

Synopsis of Site No. 8

Site No. 8 involves quarrying operations by several fairly large sized companies. This is carried on at distances that range from about 2 to 8 miles from a suburban development located on the outskirts of a relatively large Southern metropolitan area.

The homes in this upper working-class to low middle-class area are generally relatively modest, but an explosive real estate market in the area had pushed prices up to the \$50,000 to \$100,000 range by late 1980. Many of the homeowners had purchased their homes at much lower prices in the early and mid-1960's (some houses date from the late 1960's). The area of their development had never been built on previously and had been drained by the developer. Some construction people had questioned whether the developer had been in too much of a hurry to begin construction work, failing to give the soil sufficient time to settle. The water table in this area is very high. Construction, in common with that found in most of the region, is with blocks. Swimming pools are fairly common.

There was also a trailer-park community somewhat closer to the quarrying operations. This park had been in existence for only a few years, i.e., it had been set up when the quarrying was already well developed. There were, in addition, a number of scattered houses closer in to the quarry sites, at least one of them being owned by the family owning much of the land on which quarrying was taking place. There were also a very few far more expensive houses (in the \$500,000 and up range) located adjacent to the main sub-division previously mentioned.

While some quarrying had been going on in the area prior to the opening up of the housing development, most of it (and especially the ones supposedly causing problems) had come after the homeowners had purchased their properties.

A major demand for stone and gravel had led to an enormous increase in the volume of quarrying activity over the last ten years and especially recently. In general the community did not like the quarrying, for reasons not necessarily having anything to do with blasting. A frequent complaint that was mentioned was in connection with the "dangerous" truck traffic, for example. In turn, the particular community involved and the ones closest to the quarrying derived no direct benefit from the quarrying, in terms of jobs, sales, etc.

The picture painted by the community residents was that at first the quarry blasting had not been a problem, but that it had gradually become worse and recently, very bad. Many of them were able to point to cracks in walls (along the block lines) and in internal plaster work. Some had cracks along the sides of swimming pools. There were numerous reports of rattling pictures (that even "jumped off their hooks"), rattling crockery, windows that would not close, sinking driveways and pools, etc. Stories of "feeling the vibrations run through the house" were reported.

The responses of the quarry owners to complaints were varied, but generally negative (from the citizens' viewpoint). One quarry owner in particular was singled out as being only interested in his profits with no concern for the community. His quarry was particularly seen as a major culprit. By contrast, another quarry owner was thought of as a responsible businessman, but explosions at his quarry were also reported as having caused problems. The quarry operators were taking the position that the observable cracking was a settlement problem and not the result of their blasting, which they claimed was too far away to cause damage (generally over 3 miles), especially given the fact that they were keeping within the regulated limits (as evidenced by the records of the vibrations monitoring firm that was being used.)* The insurance companies had refused to honor damage claims.

Not satisfied with this response, the citizens had developed an informal citizens' organization to fight the quarries. They were keeping records of blasts and damages they believed associated with the blasting. Awareness of the blasting was intensive; some homeowners would wait at home to "catch" the blasts, some had appeared on a TV news program. The trailer-park owner had even rented his own seismograph to monitor the blasts. Their attempts to enlist government support had been frustrating to them. As they saw it, the local government (city and county) people and state officials even up to the governor all had vested interests in the construction business, the quarrying and the ownership of the land on which the quarrying was going on; naturally (claimed the residents) they were not responsive to the community complaints. There were even accusations that on those occasions on which over-blasts occurred, the records were being deliberately lost. They felt they had nowhere to turn. They had received some support from their Congressional Representative.

Some studies of vibration levels of test blasts, using different technologies, were being conducted with some Bureau of Mines assistance--this being a known "hot spot" site (and the reason we had selected it for study). There was some evidence that the use of different blasting technologies did have an effect on the vibration levels recorded.

There were no complaints regarding loss in property value. In fact none could be demonstrated; prices of homes in the development had risen pretty much in line with price increases in neighboring areas. Realtors tended to downplay the blasting problem. There had been complaints from the local school, a nearby hotel and from a large hospital located in a neighboring suburb. The Administrator of this hospital had written a letter of support for the complaining residents to the local congressman. In a later conversation he had indicated that while there had been no actual problem at the hospital, he was concerned

* It was our assessment that they were using antiquated and inappropriate seismic devices; more up-to-date equipment was said to be "too expensive."

by what could happen if a blast were to upset delicate instruments during critical micro-surgery.

The process of filing law-suits had only just begun. The people in the sub-division did not yet see themselves as ready and had been told they would get no support from the County. Several in the trailer-park had retained a lawyer. He had been in touch with some of the quarries. He indicated that the "most responsible one" did not want litigation but would "not do much to prevent it;" they had made no "repair overtures." He indicated that four quarrying companies were banding together over the issue. The lawyer felt he had a good case because he had "discovered" that dynamite was considered inherently dangerous.

Observations by members of the research team during some of the test blasts confirmed noticeable vibrations in two separate houses on two occasions. The possibility of air blast effects was also suggested. Discussions with various county officials (who did not appear themselves to be overly knowledgeable about blasting and its effects) provided a variety of differing opinions, ranging from air blast explanations to vibration effects--caused (some claimed) by the dredging out of sand from the cavernous sub-soil rock structure and its replacement by water (which they believed acted to transmit vibrations over the unusually long distances involved) to soil settlement effects and the lack of footings in some structures.

There had been little in the way of public relations or educational efforts on the part of the quarries to help their cause or to improve community understanding regarding the nature of blasting. It was our observation that this level of understanding was very low, well below that that would have resulted from reading one of the available citizens' blasting handbooks prepared by citizen groups from other regions. In turn the quarries did not publish blasting schedules or provide any form of warning, contributing to the shock and surprise dimension of the blasting; and they occasionally blasted on a Saturday, it was claimed. The citizenry response to the blasting in this poor social context--the very antithesis of what we have described as a culture of mining and the development of a modus operandi--was to call for a complete stop to all blasting and dredging, no real interest in finding a "solution" or in "reasonable damages" but rather to "close the quarries, have them move away." The unofficial head of the citizens' group was going even further; he wanted to just move away, in frustration and (as he claimed) because he had become black-listed and could no longer obtain contract work (he was a one-man independent earth mover contractor).

In summary, we have non-mining (in this case non-quarrying) culture metropolitan communities with little or no direct economic stake in the quarrying finding themselves to be increasingly subjected to what they see as an undesirable enterprise. These enterprises have come in and made the roads unsafe, the area dusty, they produce sudden explosions, airblasts and vibrations, and so forth. Technically, a very complex geologic situation (and perhaps the cumulative effects of dredging in the location) is producing a condition that may be magnifying, prolonging and extending vibrations and vibration effects beyond that normally found acceptable. This is occurring with respect to housing that may not have been well built in the beginning, on land that has great potential

for generating subsidence, cracks, etc. The cumulative combination effects of vibrations, airblasts, settling are very difficult to unravel. The quarries do little to allay citizen concerns and fears. Those involved in making judgements (officials, citizens) are not very expert, and there is little mutual trust. The citizens feel frustrated, the quarry personnel believe themselves to be in the right and operating well within regulatory requirements. No one can see or is willing to entertain any compromise; each party sees the fault as lying entirely with the other. The situation has become a "hot spot" with growing and potentially major political and economic ramifications.

Based on our observations, the situation is atypical, a consequence of a highly complex interaction of idiosyncratic conditions. It must be dealt with as a special case; compromises and adjustments are likely to be required from both sides, following a more substantial techno-social-economic study than has taken place to date. The situation at Site No. 8 (and other such special cases) must not be allowed to become a basis for general nation-wide regulations.

THE LIST OF DATA ELEMENTS

The list of data elements given under item 1. below is a tentative list developed during Phase One for the research of Phase Two. In many cases, multiple indicators were proposed to triangulate in on variables that are difficult to measure. An earlier draft was reviewed at a workshop which included CISST project team members and several persons having expert knowledge of various aspects of blasting and blasting impacts.

The data elements were pilot tested in the field to further sharpen and improve them in terms of their (a) relevance and (b) availability. It was seen to be unnecessary and frequently unfeasible to measure every single element in every case. Nevertheless, the list of data elements represents a field of reference that may facilitate future investigations and alert researchers to potentially important issues and their respective measures. We recognized the fact that some of the variables and indicators would be more important and/or more applicable than others. The field tests allowed us to modify the list in order to fit the empirical situations.

The specific field data collection protocol used was based on the general outline shown under item 2. below, together with as many of the individual issues taken from list 1 as were relevant in each situation. The areas of questioning in list 2 are organized under headings relevant for the various types of people interviewed.

1. CLASSIFICATION OF DATA ELEMENTS

1. There are three basic categories of data elements for this study
 - A. Elements related to the Behavior of the mining company in its setting.
 - B. Elements related to the Impacts of such behavior of the Company in its setting.
 - C. Elements that Moderate (Moderators) the other types of elements by categorizing, moderating and describing aspects of the interaction between the Behavior elements and the Impact elements.
2. Each type of data element is classified by the following hierarchy:
 - A. Category (of behavior, impact or moderation)
 - 1.1 Sub category
 - (a) variable
 - (1)
 - (2) Indicators
 - (3)
 - (b) (1)
 - (2)
 - (3)

A. BLASTING BEHAVIOR ELEMENTS

A.1 Stripping/Quarrying Process

<u>Variables</u>	<u>Indicators</u>
(a) Type of blast	(1) charge weight (2) delay system (3) initiation type
(b) Frequency of blast	(1) number of blasts (shots) per time period (day)
(c) Intensity of blast	(1) powder factor (2) total duration time of blast
(d) Pre-blasting survey	(1) characteristics of survey
(e) Mining method and handling	(1) type of geology (2) type of terrain
(f) Type of equipment used	(1) bucket capacity
(g) Efficiency of equipment	(1) age of equipment used

B. IMPACT ELEMENTS

B.1 Economic Impacts on the Community

1.1 Employment

<u>Variables</u>	<u>Indicators</u>
(a) Employment rate	(1) no. of people employed by mine as proportion of total employ- ment in area
(b) Wage levels/income	(1) average earnings
(c) Change in local skills educational levels	(1) new professions developed due to certification requirements (2) local colleges set-up

1.2 Commercial Activity

<u>Variables</u>	<u>Indicators</u>
(a) Businesses/services in area	(1) number of new businesses in area
(b) Tourism levels	(1) number of people visiting the site (area)
(c) Agricultural production	(1) land use
(d) Revenues	(1) community tax base (2) tax and land use revenues
(e) Local government expenses	(1) costs of negotiation and administration (2) repairs and maintenance of public buildings, roads, etc. (blast related)
(f) Individual expenses and revenues	(1) insurance rates (2) property values (3) damages and repair costs (4) royalties (5) unreimbursed damage costs (6) costs of legal/technical services (7) cost of physicians

- | | |
|-------------------------------|--|
| (g) Community action programs | (1) donated labor |
| | (2) opportunity cost of attending to blasting issues |
| | (3) information costs |

B.2 Economic Impacts on the Company

2.1 Expenditures and Costs

<u>Variables</u>	<u>Indicators</u>
(a) Capital costs	(1) cost of new blasting equipment purchased
	(2) cost of excavation equipment purchased
	(3) cost of new excavation equipment leased
(b) Damage/annoyance settlements	(1) legal fees expended
	(2) expert fees expended
	(3) insurance rates
	(4) pre-blasting costs to obtain waiver on damage
(c) Productivity	(1) maintenance costs
	(2) powder factor and drilling factor
	(3) changes in blasting and drilling costs
(d) Administrative costs	(1) cost of additional departments required or created
	(2) cost of additional company functions to deal with claims
	(3) training costs
	(4) total costs of claims administration
	(5) costs of claims prevention and good will
	(6) donation to community (financial, equipment, manpower)
	(7) donation to community (posted bonds)

- | | |
|-----------------------|--|
| (e) Information costs | (1) cost of circulation of information |
|-----------------------|--|

B.3 Technical Impacts on the Community

- | <u>Variables</u> | <u>Indicators</u> |
|----------------------------|--|
| (a) Technology acquisition | (1) crack origin estimation techniques |

B.4 Technical Impacts on Company

- | <u>Variables</u> | <u>Indicators</u> |
|--|---|
| (a) New techniques and implementation | (1) training of higher skilled people
(2) consultants to bring in new techniques
(3) instrumentation costs
(4) research on monitoring techniques and equipment |
| (b) R&D (monitoring and blasting) | (1) indirect costs for developing new techniques
(2) basic research costs
(3) instrumentation research costs |
| (c) Change in efficiency due to new techniques | (1) quantity of overburden or partial layer broken by a shot
(2) number of shots needed to break a given number of overburden or partial layers |
| (d) Choices of what factors to measure | (1) frequency air blasts
(2) long distance crash measurements
(3) re-evaluation of blast information |

B.5 Social Impacts on Community

5.1 Quality of Life

<u>Variables</u>	<u>Indicators</u>
(a) Residential quality	(1) housing starts (2) vacancy rates of apartments/houses (3) mortgage/home loan availability and usage
(b) Decline in quality of neighborhood	(1) availability of social services (2) recreational land use (3) range/number of cultural activities (4) distance of services and recreation (5) shutting down of roads (6) disruption of community

B.6 Social Impacts on Company

<u>Variables</u>	<u>Indicators</u>
(a) Image/community relations	(1) level of externally initiated public relations activity (2) number of editorials (3) picketing
(b) Demands on company	(1) community expectations (2) community views of company responsibility (3) community demand for restitution
(c) Political problems/corporate annoyance	(1) company involvement in local politics (2) frequency/intensity of local government complaints (3) regulatory conflicts and intensity of contradictions

- | | |
|--|---|
| (d) Union activity | (1) level of company interaction
with unions (blasting
related) |
| (e) Physical harm to
employees | (1) accident reports of
employees
(2) insurance costs |
| (f) Mental aggravation
to employees | (1) union complaints
(2) incidents reported. |

C. MODERATING ELEMENTS

These data elements are designed to allow for the categorization of the relationship between blasting and its potential impacts. This categorization will be done in terms of the company in its setting -- namely, the mine and the adjacent community.

The Moderating elements thus serve as intervening variables in this relationship by categorizing, moderating and describing aspects of the interaction between the Behavior and Impact elements.

C.1 Community Characteristics

<u>Variables</u>	<u>Indicators</u>
(a) Age of community	
(b) Construction history of dwelling	(1) type of construction (2) age of structures
(c) Population characteristics	(1) density and distribution (2) age of structure (3) mobility
(d) Social characteristics	(1) education levels (2) structure of governing body

C.2 Company Characteristics

<u>Variables</u>	<u>Indicators</u>
(a) Type of ownership	(1) public/private; local/non-local (2) concentration of ownership
(b) Image of company	-
(c) Ownership affects on mining quality	(1) e.g.: oil vs. coal
(d) Company assets	-
(e) Access to resources	(1) capital, labor, skills
(f) Access to main suppliers	(1) equipment, blasting material and services
(g) Unionization of company	(1) union vs. non-union

- (h) Political leverage
of company
- (i) Quality of taking care
of complaints/damages,
vs. letting insurance
do it
- (j) Company charter

C.3 Site Characteristics

<u>Variables</u>	<u>Indicators</u>
(a) Size of mine	-
(b) Type of mine	(1) coal, copper, etc.
(c) Depth of over- burden/parting layer	-
(d) Terrain/geography	(1) hilly, flat, steep slope
(e) Quantity of deposits	
(f) Quality of deposits	
(g) Production levels	
(h) Location of crushers	
(i) Weather/wind directions/ temperature	
(j) Terrain transmission characteristics	
(k) Distance from other mines/quarries owned by company	
(l) Time period company has been in area	

C.4 Local Industrial Infrastructure

<u>Variables</u>	<u>Indicators</u>
(a) Overall industry infrastructure	(1) patterns of ownership (2) power structure (3) technological base and gaps (4) industry norms and ideology

- (5) characteristics of states, variations in, e.g.: regulations
- (6) linkages between industry, academics, government and consultants
- (7) role of function of Bureau of Mines and funding
- (b) Local industrial infrastructure
 - (1) mix of industry
 - (2) dependence of community on local firms and mines
 - (3) interdependence of local firms and mines
 - (4) distance between mines/quarries
 - (5) support services and businesses
 - (6) variations by states

C.5 Community-Company Interaction

<u>Variables</u>	<u>Indicators</u>
(a) Dependence of community on company and vice-versa	-
(b) Existence of point planning activities	-
(c) Company participation in government, planning agencies	-
(d) Local laws/constraints on company	(1) zoning, planning commissions
(e) Company participation	(1) training

C.6 Legal System

<u>Variables</u>		<u>Indicators</u>
(a) Federal laws and regulations	-	
(b) State laws and regulations	-	
(c) Local laws and regulations	-	
(d) Prior settlements/legal precedents		

2. GUIDELINES FOR INTERVIEWS

Instructions to Field Interviewers

Use the following notes as a general guideline, in conjunction with as much input from the Data Elements list as appropriate. Fundamentally, allow the interviewees as much opportunity as possible to tell their story and express their views, as they see and feel it.

The types of persons to be interviewed are (again) a guideline only. Seek out anyone else that is reported to you as likely to be a useful informant. This is specifically called for in the guideline questions for various types of people, but do not be limited by that; any lead is fine. The list does not include mine personnel since they are being interviewed separately.

BASIC QUESTIONS

1. Which of the nearby mines do you consider good/Bad in terms of their behavior in general and blasting in particular?
2. How dependent is community on mines?
3. What is the difference in blasting behavior between union/nonunion mines?
4. Who are people that tend to complain about mining (and blasting in particular)? (damage, annoyance, etc.)
5. What are methods/procedures for dealing with complaints in the community, and by the mines?
6. Are there community action groups now or in past 5 yrs.? How active are they? Who participates? How do they operate? Are their activities of any consequence in mining area? If they failed, why? (in your opinion).

CITIZENS

1. Obtain general information on the person and family, home, etc. (occupation, type of home, cost, distance to mines construction, grounds, how long lived there, relations to mining, previous places lived, where grew up).

2. Experience with mines/blasting - any problems, complaints, damage, annoyance. Under what conditions, how often, since when, etc., costs to deal with, non-blasting problems with mines.
3. Their views of mines' behavior (frequency of blasts, notice given, time of day, which days, concern of mines, willingness to deal with problems, community behavior).
4. Complaints process - to whom, when, what results, do they know who to complain to, awareness of blasting regulations, have they ever formed (belonged to) a group of annoyed citizens, any legal actions (taken/planned).
5. Property value effects.
6. Behavior of government officials, (county, city, state, etc.)
7. Any changes/actions they see needed, solutions, etc.
8. Special problems they are encountering (e.g. opposition).

MAYOR/CITY MANAGER

1. Names and addresses of key informants.
2. Was your office ever asked to intervene with regard to blasting effects? What was the outcome?

3. Was town hall ever the site of public meeting regarding the effects of blasting behavior of mines? Was it requested?
4. How do mines alert population to blasting? What is role of city/town hall in these procedures? Are these adequate?
5. Do you recall any damages to public structures due to blasting? Estimate cost of repairs.
6. What is relationship between town govt. and mines? How well do they communicate? How often? What are main issues? Are these documented?
7. How aware is community regarding blasting and its impacts?
8. Is blasting, in your view, really the cause of complaints on mining activities?

POLICE/SHERIFF

1. Is your office part of the mechanism for complaints on mining activities?
2. How would you classify or describe relations between community and mines?

COUNTY PLANNING/ZONING

- *1. Get Map of county with School Dist. lines, Annual Reports, list of mines in county, housing starts + business starts, regulations imposed or removed on mining activities in past 3 yrs., population trends toward or away from mines (last 5 yrs.).
2. Do you recall committee meetings in past year or two in which blasting and its effects were discussed? What was outcome?
3. Are there any specific documents dealing with blasting produced by the committee? Is there specific correspondence with towns or mining companies?
- *4. Check updated map of county, mark school dist. lines, churches, other public buildings in relevant towns.
5. Obtain names + addresses of key informants in towns.
- *6. Get good map that lists mines.

*
MAPS

COUNTY ENGINEER

1. Locate on updated map, water lines and other public works.
2. Do you recall any complaints about structural damage to public works from blasting activities?
3. In past 3 yrs., were any repairs made to public works because of damage caused by blasting? Estimate cost.

REAL ESTATE/BOARD OF REALTORS

1. Have people sold houses near mines due to blasting (noise, annoyance, etc.)? Is turnover in houses near mines higher than those farther away? How much higher?
2. Have you had difficulties in selling houses near mines?
3. Is reason for selling really because of blasting? What other reasons do you think prompted sale?
4. What are population mobility trends, to and from mines?
5. In recent years, have property values near mines declined, in relation to rest of community? Why? How much of the reason is blasting?
6. Can you give us examples from recent sales?

CHAMBER OF COMMERCE

1. Names and addresses of key informants.
2. Ask him to detail population trends (are people leaving town or is there growth)?
3. In past 3-5 yrs., was Chamber asked to intervene or take action in issues related to effects of blasting?
(damage to property, annoyance, etc.)
4. What is the general relationship between mines and community? Define it (hostile, friendly, indifferent). Relate such attitudes to degree of dependence of the town to mine.
5. How do mines alert population to blasting? What methods do they use? (general schedules, advertize in paper, etc.)
How often are notices given? How much time prior to blasting? Are methods satisfactory?
6. How would you rate behavior of mines in general, and with regard to blasting in particular?
7. Who to see in mining communities other than this town?

COMMUNITY ACTION GROUPS

1. Do you have records of your activities?
2. History and structure of group: why formed? Failed? Changes? Breakdown of membership.
3. Of issues you take action on, how much emphasis is put on blasting and its effects?
4. How much support do you get from community?
5. What are your methods of action (public meetings, publications, notices in media)?
6. How effective are you? History of successes and failures? Why? In general, what have you achieved?
7. What is reaction of mines to your activities?
8. What are your plans for the future?

NEWSPAPER

(Owner and/or Reporter)

1. In past 1-2 yrs., have there been editorials or notices in paper regarding mining behavior and blasting in particular?
2. How much of community awareness to blasting is reflected in the paper?
3. How would you classify the relations between the community and the mines? (Good, hostile)

UNION HEADQUARTERS

1. Mainly #3 of basic questions:
what is the difference in blasting behavior between union/nonunion mines?

PART TWO

DEMOGRAPHIC ANALYSIS
OF
DENSITY PATTERNS NEAR SURFACE COAL MINES

The potential for cracking and annoyance impacts of surface mine blasting is directly related to the number of residential and other structures at varying distances from blasting sites. To prove an estimation of such density patterns, the area within 5000' of a random sample of 101 current (1978-79) surface mine permit areas in four states was analyzed. Permit boundary data was obtained from state regulatory agencies and was mapped onto 7 $\frac{1}{2}$ ⁰ U.S.G.S. Topographical maps.* A proforma was developed for recording the data from these maps.

The topographical maps were chosen because they: a) provide sufficient information about terrain characteristics; b) identify and distinguish between relevant structures; and c) are drawn at a useable level of scale. Other documents were considered but were found to be less adequate.**

In addition to the aggregate analysis, analyses are provided separately for steep, rolling hill and flat terrains.

It is to be noted that the density patterns discussed below technically apply only to the permit perimeter. Density patterns for actual blasting sites would decrease as the distance of blasting sites from the permit boundary increases.

In addition to the permit analysis, a permit/section comparative analysis is provided.

* To ensure current accuracy, only 1975-79 maps were used, and census figures were examined to control for significant population growth in the period after the latest updating of the maps.

** In particular, NASA and other aerial photographs were examined but found not to meet the criteria just noted, and additionally would have required a high cost for data collection.

I. RESIDENTIAL DENSITY PATTERNS: CURRENT (1978-79) PERMITS

Analysis of density patterns for residential structures reflects the following distance relationships to permit boundaries (as is illustrated in Figure 1):

- Zone 1 -- within the permit boundaries
- Zone 2 -- 0' to 500' from the permit boundary
- Zone 3 -- 500' to 1000' from the permit boundary
- Zone 4 -- 1000' to 2500' from the permit boundary
- Zone 5 -- 2500' to 5000' from the permit boundary

The A and B Tables provide a summary of the permit analysis of residential density patterns for the total sample and separately for steep, rolling hill and flat terrains. The A and B Tables indicate a low density pattern near permit boundaries and a pattern of increasing density as distance from the permit boundary increases -- with the most significant rate of increase in density occurring between 1000' - 1500'.

The tables show density patterns both before and after adjustment for major value shifts at the high end of density patterns. Where a value shift is sudden near the 95% level, this is used as the cut-off for adjustment. Where no single major value shift is present, the 95% level is used as the cut-off for adjustment.

Sudden high value shifts bias the analysis towards the high side. Thus, the after-adjustment figures provide a more accurate representation of average density patterns. However, the sudden value shifts at the high end do indicate that larger density patterns (while not prevalent) can occur, especially in the 1000' - 5000' range.

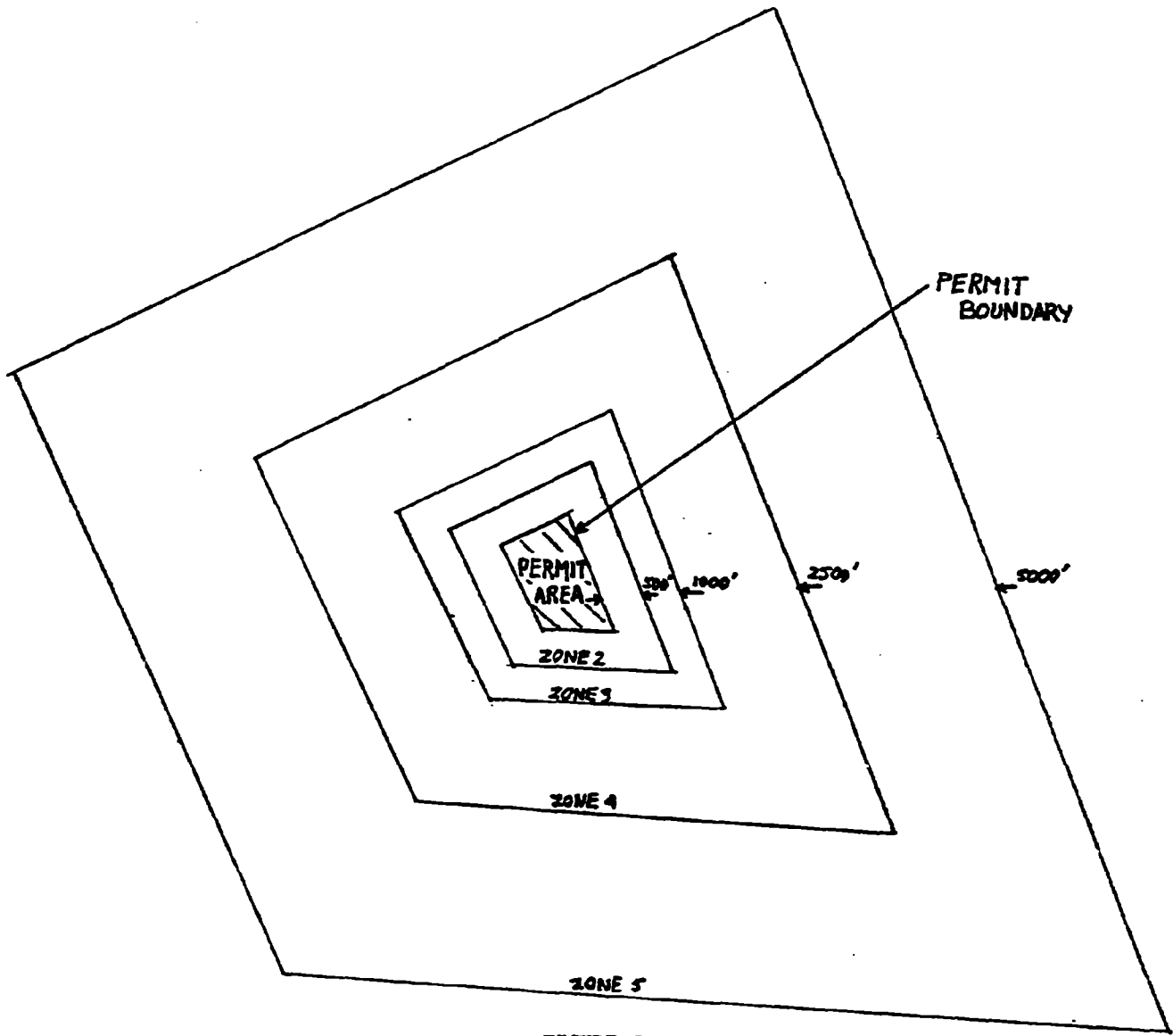


FIGURE 1
 DISTANCE ZONES FROM PERMIT BOUNDARY:
 DEMOGRAPHIC ANALYSIS OF RESIDENTIAL DENSITY

- KEY: ZONE 1: Within permit boundary
 ZONE 2: Within 500' of permit boundary
 ZONE 3: 500'-1000' from permit boundary
 ZONE 4: 1000'-2500' from permit boundary
 ZONE 5: 2500'-5000' from permit boundary

Figure 1 illustrates both the distance factors of the five Zones and the irregular shape of permit areas. The figure shape is hypothetical. Actual permit boundary (and thus, corresponding distance zones) would often tend to be even more irregular in shape or pattern.

Statistics	Zones				
	1	2	3	4	5
Mean	0.465	3.099	5.089	21.307	41.681
Adjusted Mean	0.465	2.302*	3.495*	17.021*	35.122*
Standard Deviation	1.188	4.631	7.575	25.255	44.119
Adjusted Standard Deviation	1.188	3.078	3.789	16.956	31.402
Median	0.131	1.219	2.333	13.556	28.500
Adjusted Median	0.131	1.063	2.133	12.167	26.500
Range	6.000	21.000	41.000	124.000	222.000
Adjusted Range	6.000	15.000	14.000	74.000	138.000

Table A

Statistical Summary of Data Before and After Adjustment:
All Residential Units

* Zones 2 and 3 represent 500' intervals while Zones 4 and 5 represent 1500' and 2500' intervals respectively. Thus, the rate of increase in mean values may be reanalyzed in terms of 500' intervals for all zones as follows:

Increase in Adjusted Mean per 500' Interval

From Zone 2 to Zone 3 — 1.193
 From Zone 3 to Zone 4 — 4.509
 From Zone 4 to Zone 5 — 3.620

Zone	Mean	Adjusted Mean	Range	Adjusted Range	Minimum Density Probabilities# (After Adjustment)					Probability of No Units in Zone
					25%	50%	70%	90%	95%	
Zone #1	0.465	-	6	-	0	0	0	1 (91.1%)	3 (94.1%)	79.2%
Zone #2	3.099	2.302	21	15	0	1 (57.3%)	3 (74.0%)	6 (89.6%)	9 (96.9%)	40.6%
Zone #3	5.089	3.495	41	14	0 (25.3%)	2 (55.8%)	4 (68.4%)	9 (94.7%)	11 (94.7%)	25.3%
Zone #4	21.307	17.021	124	74	5 (28.1%)	12 (51.0%)	17 (69.8%)	40 (90.6%)	56 (95.8%)	1.0%
Zone #5	41.681	35.122	222	138	13 (26.7%)	26	40	73	104 (95.6%)	1.1%

Table B

Statistical Summary of Residential Units: All Cases

* Zones 2 and 3 represent 500' intervals while Zones 4 and 5 represent 1500' and 2500' intervals respectively.

Arabic numbers represent maximum numbers of units at varying approximate percentiles of total sample for each zone. Percentage figures in parentheses represent actual percentile (where these vary from the column heading percentages).

Zone	Mean	Adjusted Mean	Range	Adjusted Range	Minimum Density Probabilities# (After Adjustment)					Probability of No Units in Zone
					25%	50%	70%	90%	95%	
Zone #1	0.182	0.182	2	2	-	-	-	0	1	83.6%
Zone #2	2.291	1.736	18	9	-	0	2	5	6	45.3%
Zone #3	3.327	2.865	12	10	0	1	3	8	9	28.8%
Zone #4	15.236	11.904	108	47	4	9	15	24	28	1.9%
Zone #5	33.164	23.843	201	75	8	21	29	50	63	2.0%

Table B.1

Statistical Summary of Residential Units: Contour Stripping Mining Areas

* Zones 2 and 3 represent 500' intervals while Zones 4 and 5 represent 1500' and 2500' intervals respectively.

Arabic numbers represent maximum numbers of units at varying approximate percentiles of total sample for each zone. Percentage figures in parentheses represent actual percentile (where these vary from the column heading percentages).

Zone	Mean	Adjusted Mean	Range	Adjusted Range	Minimum Density Probabilities# (After Adjustment)					Probability of No Units in Zone
					25%	50%	70%	90%	95%	
Zone #1	0.793	0.793	6	6	-	-	0 (72.4%)	4 (93.1%)	5 (96.6%)	72%
Zone #2	3.138	1.926	21	7	-	1 (59.3%)	2 (74.1%)	6 (92.6%)	7 (100%)	40.7%
Zone #3	6.793	4.955	41	28	1 (22.7%)	2 (45.5%)	5 (77.3%)	8 (86.4%)	14	9.1%
Zone #4	25.345	22.448	124	89	6 (24.1%)	14 (55.2%)	18 (69.0%)	51 (89.7%)	74 (96.6%)	0
Zone #5	58.759	48.741	222	137	22 (25.9%)	40 (48.1%)	58 (70.4%)	104 (92.6%)	125 (96.3%)	0

Table B.2

Statistical Summary of Residential Units: Contour/Area Stripping Mining Areas

* Zones 2 and 3 represent 500' intervals while Zones 4 and 5 represent 1500' and 2500' intervals respectively.

Arabic numbers represent maximum numbers of units at varying approximate percentiles of total sample for each zone. Percentage figures in parentheses represent actual percentile (where these differ from the column heading percentages).

Zone	Mean	Adjusted Mean	Range	Adjusted Range	Minimum Density Probabilities# (After Adjustment)					Probability of No Units in Zone
					25%	50%	70%	90%	95%	
Zone #1	0.538	0.538	4	4	0	0	0	3 (92.3%)	4 (100%)	84.6%
Zone #2	4.692	4.692	19	19	0 (30.8%)	2 (46.2%)	4 (69.2%)	15 (92.3%)	19 (100%)	30.8%
Zone #3	5.538	5.538	25	25	0	1 (53.8%)	3 (69.2%)	8 (84.6%)	25 (100%)	38.5%
Zone #4	23.385	23.385	69	69	5 (23.1)	12 (46.2%)	26 (69.2%)	67 (92.3%)	71 (100%)	0%
Zone #5	39.0	28.788	120	55	15 (22%)	31 (55%)	39 (77%)	40 (88%)	55 (100%)	0%

Table B.3

Statistical Summary of Residential Units: Area Stripping Mining Areas

* Zones 2 and 3 represent 500' intervals while Zones 4 and 5 represent 1500' and 2500' intervals respectively.

Arabic numbers represent maximum numbers of units at varying approximate percentiles of total sample for each zone. Percentage figures in parentheses represent actual percentile (where these vary from the column heading percentages).

ZONE 1

RESIDENTIAL STRUCTURES WITHIN THE PERMIT BOUNDARY

As Tables 1.1 and 1.2 illustrate, the density of residential structures within permit boundaries is quite small. In 79.2% of the cases, there are no structures and one structure or less in 91.1% of the cases. The maximum number of structures is only 6 (in only 1% of the cases). This is consistent with visual observations of mine sites during field research.

Field observations further suggest that: 1) some of these structures represent mining company site offices and/or abandoned buildings; and/or 2) many represent residences purchased by mine companies and are no longer occupied.

For Zone 1, no adjustments are needed for sudden shifts in value.

Mean	0.465
Standard Deviation	1.188
Median	0.131
Maximum No. of Structures	6.000
Minimum No. of Structures	0.000
Range	6.000

Table 1.1
Summary of Residential Structures in Zone 1

No. of Houses	Relative Frequency (%)	Cumulative Frequency (%)
0	79.2	79.2
1	11.9	91.1
2	2.0	93.1
3	1.0	94.1
4	3.0	97.0
5	2.0	99.0
6	1.0	100.0

Table 1.2
Frequency of Residential Structures in Zone 1

ZONE 2

RESIDENTIAL STRUCTURE WITHIN 0'-500' OF PERMIT BOUNDARIES

Tables 2.1 and 2.2 indicate that in the critical "near" zone of 0'-500' from permit boundaries, density patterns are generally low. In 38.6% of all cases, there are no houses; only one or less houses in 54.5% of all cases; and four or less houses in 76.2% of all cases. Further, there is a moderate frequency jump from 15.8% to 8.9% between the one and two house levels. Thereafter, the frequency variation is small and consistently declining relative to an increasing number of houses in the zone.

The maximum number of houses found in Zone 2 is 21, but at the 95% level (all cases) the maximum is 15.

In an analysis of frequencies, extreme cases represented by sudden jumps in frequency values may need to be eliminated to provide a more true representation of distributions. Since there is no sudden shift in density values, the 95% level is used for adjustment. As is illustrated in Tables 2.1 and 2.2, adjustments for high values is of marginal benefit for Zone 2.

	Before Adjustment	After Adjustment
Mean	3.099	2.302
Standard Deviation	4.631	3.078
Median	1.219	1.063
Maximum No. of Structures	21.0	15.000
Minimum No. of Structures	0.0	0.0
Range	21.0	15.000

Table 2.1
Adjusted Summary of Residential Structures in Zone 2

No. of Houses	Before Adjustment		After Adjustment	
	Relative Frequency (%)	Cumulative Frequency (%)	Relative Frequency (%)	Cumulative Frequency (%)
0	38.6	38.6	40.6	40.6
1	15.8	54.5	16.7	57.3
2	8.9	63.4	9.4	66.7
3	6.9	70.3	7.3	74.0
4	5.9	76.2	6.3	80.2
5	5.0	81.2	5.2	85.4
6	4.0	85.1	4.2	89.6
7	4.0	89.1	4.2	93.8
9	3.0	92.1	3.1	96.9
11	1.0	93.1	1.0	97.9
12	1.0	94.1	1.0	99.0
15	1.0	95.0	1.0	100.0
16	1.0	96.0		
18	2.0	98.0		
19	1.0	99.0		
21	1.0	100.0		

Table 2.2
Frequency of Residential Structures in Zone 2

ZONE 3

RESIDENTIAL STRUCTURES WITHIN 500'-1000' OF PERMIT BOUNDARIES

Zone 3 shows a somewhat increased density pattern. The maximum number of houses increases to 41 (from 21 in Zone 2). While there is a strong shift in density values beyond 14 houses, it is to be noted that at the 94.1% level (all cases), there are 14 or less houses in Zone 3 and 12 houses in Zone 2.

A similar comparison may be made of the mean values in Zones 2 and 3. Before adjustment for high values, the mean value increases from 3.009 to 5.089. However, when adjusted for high values, the mean value increase is smaller (from 2.302 to 3.495).

Overall, the density pattern in Zone 3 is still relatively low. In 23.8% of all cases, there are no houses; two or less in 52.5% of all cases; and six or less in 74.3% of all cases. After the level of four houses is reached, variation is small and declining for most remaining density values. There are significant and irregular jumps in density values beyond the level of fourteen houses.

In Zone 3, adjustment for high density values is significant relative to maximum size and mean density value, but less so for frequencies.

	Before Adjustment	After Adjustment
Mean	5.089	3.495
Standard Deviation	7.575	3.789
Median	2.333	2.133
Maximum No. of Structures	41.000	14.0
Minimum No. of Structures	0.000	0
Range	41.000	14.0

Table 3.1

Summary of Residential Structures in Zone 3

ZONE 3

No. of Houses	Before Adjustment		After Adjustment	
	Relative Frequency (%)	Cumulative Frequency (%)	Relative Frequency (%)	Cumulative Frequency (%)
0	23.8	23.8	25.3	25.3
1	13.9	37.6	14.7	40.0
2	14.9	52.5	15.8	55.8
3	8.9	61.4	9.5	65.3
4	3.0	64.4	3.2	68.4
5	5.9	70.3	6.3	74.7
6	4.0	74.3	4.2	78.9
7	4.0	78.2	4.2	83.2
8	4.0	82.2	4.2	87.4
9	3.0	85.1	3.2	90.5
10	2.0	87.1	2.1	92.6
11	2.0	89.1	2.1	94.7
12	2.0	91.1	2.1	96.8
14	3.0	94.1	3.2	100.0
23	1.0	95.0		
25	2.0	97.0		
28	1.0	98.0		
40	1.0	99.0		
41	1.0	100.0		

Table 3.2

Frequency of Residential Structures in Zone 3

ZONE 4

RESIDENTIAL STRUCTURES WITHIN 1000'-5000' OF PERMIT BOUNDARIES

Zone 4 shows an increased density pattern compared to Zone 3. The maximum number of houses is 124 (compared to 41 in Zone 3). At the 95% level (all cases), the range in Zone 4 is 74 (compared to 23 at the 95% level and only 14 at the 94.1% level in Zone 3).

The mean for Zone 4 also shows a significant increase compared to Zone 3 — 17.021 and 5.673 respectively (after adjustment). Since Zone 4 represents a 1500' interval while Zone 3 represents a 500' interval, further analysis is needed to determine the relative rate of increase between these zones. Thus, it is noted that the adjusted mean for Zone 3 represents an increase of 1.193 over the adjusted mean for Zone 2. Zone 4 represents an increase of 13.526 over the adjusted mean for Zone 3 — or an equivalent increase of 4.509 for each 500' interval within Zone 4.

It is also noted that in Zone 3, density value changes show a strong sudden shift at 14, and significant but irregular shifts after 14. In Zone 4, strong or irregular shifts in density values do not begin to occur until after the value of 28.

	Before Adjustment	After Adjustment
Mean	21.307	17.021
Standard Deviation	25.255	16.956
Median	13.556	12.167
Maximum # of Structures	124.0	74.0
Minimum # of Structures	0.0	0.0
Range	124.0	74.0

Table 4.1

Summary of Residential Structures in Zone 4

# of Houses	Before Adjustment		After Adjustment	
	Relative Frequency (%)	Cumulative Frequency (%)	Relative Frequency (%)	Cumulative Frequency (%)
0	1.0	1.0	1.0	1.0
1	3.0	4.0	3.1	4.2
2	4.0	7.9	4.2	8.3
3	5.0	12.9	5.2	13.5
4	5.9	18.8	6.3	19.8
5	7.9	26.7	8.3	28.1
6	5.0	31.7	5.2	33.3
7	4.0	35.6	4.2	37.5
8	2.0	37.6	2.1	39.6
9	4.0	41.6	4.2	43.8
10	1.0	42.6	1.0	44.8
11	3.0	45.5	3.1	47.9
12	3.0	48.5	3.1	51.0
13	1.0	49.5	1.0	52.1
14	8.9	58.4	9.4	61.5
15	2.0	60.4	2.1	63.5
16	3.0	63.4	3.1	66.7
17	3.0	66.3	3.1	69.8
18	2.0	68.3	2.1	71.9
19	2.0	70.3	2.1	74.0
20	1.0	71.3	1.0	75.0
21	2.0	73.3	2.1	77.1
22	1.0	74.3	1.0	78.1
24	1.0	75.2	1.0	79.2
26	2.0	77.2	2.1	81.3
28	1.0	78.2	1.0	82.3
34	2.0	80.2	2.1	84.4
35	2.0	82.2	2.1	86.5
37	1.0	83.2	1.0	87.5
38	1.0	84.2	1.0	88.5
40	2.0	86.1	2.1	90.6
44	1.0	87.1	1.0	91.7
47	1.0	88.1	1.0	92.7
51	1.0	89.1	1.0	93.8
55	1.0	90.1	1.0	94.8
56	1.0	91.1	1.0	95.8
67	2.0	93.1	2.1	97.9
71	1.0	94.1	1.0	99.0
74	1.0	95.0	1.0	100.0
89	1.0	96.0		
90	1.0	97.0		
107	1.0	98.0		
108	1.0	99.0		
124	1.0	100.0		

Table 4.2

Frequency of Residential Structures in Zone 4

ZONE 5

RESIDENTIAL STRUCTURES WITHIN 2500'-5000' OF PERMIT BOUNDARIES

Zone 5 shows an increased density pattern compared to Zone 4. The maximum number of houses is 222 (compared to 124 in Zone 4). At the 94.7 level (all cases), the range in Zone 5 is 137 — compared to 74 at the 95% level in Zone 4.

The adjusted mean for Zone 5 is 35.122 — compared to 17.021 for Zone 4. This represents an increase of 18.101 or the equivalent of an increase of 3.620 for each 500 foot interval in Zone 5. Density values in Zone 5 begin to show irregular shifts only after the value of 32, with strong shifts beginning to occur only after the value of 79. Further, it may be noted that variation in the range of relative frequencies (all cases) is lower for Zone 5 (range = 4.3) than for Zone 4 (range = 8.9).

	Before Adjustment	After Adjustment
Mean	41.681	35.122
Standard Deviation	44.119	31.402
Median	28.500	26.500
Maximum # of Structures	222.0	138.0
Minimum # of Structures	0	0
Range	222.0	138.0

Table 5.1

Summary of Residential Structures in Zone 5

# of Houses	Before Adjustment		After Adjustment	
	Relative Frequency (Z)	Cumulative Frequency (Z)	Relative Frequency (Z)	Cumulative Frequency (Z)
0	1.1	1.1	1.1	1.1
1	1.1	2.1	1.1	2.2
2	1.2	3.2	1.1	3.3
3	3.2	6.4	3.3	6.7
4	3.2	9.6	3.3	10.0
5	1.1	10.6	1.1	11.1
6	1.1	11.7	1.1	12.2
7	2.1	13.8	2.2	14.4
8	1.1	14.9	1.1	15.6
9	1.1	16.0	1.1	16.7
10	2.1	18.1	2.2	18.9
11	4.3	22.3	4.4	23.3
12	1.1	23.4	1.1	24.4
13	2.1	25.5	2.2	26.7
14	1.1	26.6	1.1	27.8
15	1.1	27.7	1.1	28.9
16	1.1	28.7	1.1	30.0
17	2.1	30.9	2.2	32.2
18	2.1	33.0	2.2	24.4
19	3.2	36.2	3.3	27.8
21	2.1	38.3	2.2	40.0
22	1.1	39.4	1.1	41.1
23	4.3	43.6	4.4	45.6
24	2.1	45.7	2.2	47.8
25	1.1	46.8	1.1	48.9
26	1.1	47.9	1.1	50.0
27	1.1	48.9	1.1	51.1
28	1.1	50.0	1.1	52.2
29	3.2	53.2	3.3	55.6
30	1.1	54.3	1.1	56.7
31	3.2	57.4	3.3	60.0
32	3.2	60.6	3.3	63.3
35	1.1	61.7	1.1	64.4
39	2.1	63.8	2.2	66.7
40	2.1	66.0	2.2	68.9
41	2.1	68.1	2.2	71.1
43	1.1	69.1	1.1	72.2
44	1.1	70.2	1.1	73.3
47	1.1	71.3	1.1	74.4
48	1.1	72.3	1.1	75.6
49	1.1	73.4	1.1	76.7
50	1.1	74.5	1.1	77.8
51	1.1	75.5	1.1	78.9
52	2.1	77.7	2.2	81.1
55	1.1	78.7	1.1	82.2
58	1.1	79.8	1.1	83.3
60	1.1	80.9	1.1	84.4
63	2.1	83.0	2.2	86.7
66	1.1	84.0	1.1	87.8
67	1.1	85.1	1.1	88.9
73	1.1	86.2	1.1	90.0
75	1.1	87.2	1.1	91.1
79	1.1	88.3	1.1	92.2
99	1.1	89.4	1.1	93.3
101	1.1	90.4	1.1	94.4
104	1.1	91.5	1.1	95.6
125	1.1	92.6	1.1	96.7
131	1.1	93.6	1.1	97.8
137	1.1	94.7	1.1	98.9
138	1.1	95.7	1.1	100.0
166	1.1	96.8		
168	1.1	97.9		
201	1.1	98.9		
222	1.1	100.0		

Table 5.2

Frequency of Residential Structures in Zone 5

Structure	Distance
# of schools	Within 2500' from Permit Boundary Line
	Between 2500' and 5000'
# of highways	Within 500' from Permit Boundary Line
	Between 500' and 1000'
Total # of gas lines, well and electricity (utility) lines	Within 250' from Permit Boundary Line
	Between 250' and 500'
Other important structures	Within 2500' from Permit Boundary Line

TABLE 6

Non-Residential Structures and Corresponding Distance Criteria

II. DENSITY PATTERNS FOR NON-RESIDENTIAL STRUCTURES AND FEATURES:
CURRENT (1978-79) PERMITS

The sample of current surface mine permit areas was also examined (using the topographical maps) to determine density patterns for non-residential structures or features which might be impacted by blasting. As can be seen from Tables 7-10, there are a variety of structures other than residences which might be found at varying distances around a mine. None are found with a high level of frequency. Most importantly, it can be noted (Table 7), that schools show a low frequency ((mean = 0.042, maximum number = within 2500'). Cemeteries and churches show a moderate level of frequency within 2500' of permit boundaries (Table 10).

	Distance	
	Within 2500' of Permit Boundary	2500'-5000' from Permit Boundary
Mean	0.042	0.183
Standard Deviation	0.203	0.425
Median	0.022	0.102
Maximum # of Schools	1.000	2.000
Minimum # of Schools	0.000	0.000
Range	1.000	2.000

Table 7

General Statistics on Schools Within 5000' of Permit Boundaries

	Distance	
	Within 500' of Permit Boundary	500'-1000' from Permit Boundary
Mean	0.197	0.366
Standard Deviation	0.435	0.591
Median	0.112	0.240
Maximum # of Highways	2.000	3.000
Minimum # of Highways	0.000	0.000
Range	2.000	3.000

Table 8

General Statistics on Highways Within 1000' of Permit Boundaries

Major Gasline, Well &/or Electricity Line	Mean	Standard Deviation
Falling within 250'	0.028	0.020
Falling in between 250' and 500'	0.070	0.031

Table 9

Statistics on Gas Lines, Wells and Electricity Lines Within 500' of Permit Boundaries

Type of Structure	Frequency
Cemetery	41
Church	21
Radio/TV tower	3
Railroad	3
Airport	2
Bridge	2
Park	2
Trailer park	2
Drive-in Theater	1
Race Track	1
Tower	1
Water tank	1

Table 10

Other Structures Found Within
2500' of Permit Boundaries

III. SUPPLEMENTAL ANALYSIS OF DENSITY PATTERNS: SECTIONS CP. PERMIT AREAS

The use of actual current (1978-9) permit areas is the most accurate method of determining residential density patterns around mines. It is also a difficult method with which to obtain a large number of samples within the parameters of time and cost. A second method would be to use the section* approach. The problems associated with the section concept** make it inappropriate as the primary basis for density analysis of this study, but the ease of obtaining and analyzing sections does make it an appropriate method of supplemental analysis. Thus, in addition to the permit analysis, a section analysis of density patterns was performed for flat and rolling hill terrain.

Using the permit data, it was first determined that a representative permit would have an area of 413×10^4 sq. ft., which may be translated into a square of 2032' on each side. This 2032' square was marked off in the center of each section analyzed, and then the number of houses within 5000' of the 2032' square, using USGS topographical maps.***

A comparison of the section and permit analyses reveals the following:

- 1) Flat Terrain
 - a) There is an average (mean) of 60 dwellings within 5000' of the permit boundaries.
 - b) There is an average (mean) of 69 dwellings within 5000' of the 2032' square placed within sections.

* According to long-standing surveying practise, some states are divided by imaginary lines that run north-south and east-west (comparable in principle to the longitude/latitude concept) on a standard geographical map such as the USGS topographical maps. A subdivided area of approximately one square mile (in most cases) is called a "section" and is identified in terms of "townships" and "range".

** For example: difficulty in knowing precisely where mining is or is not currently occurring; actual mining areas do not necessarily form simple squares; not all states use the section method.

*** To ensure current accuracy in the number of dwelling units found on the topographical maps, only 1975-79 maps were used, and census figures were examined to control for significant population growth in the period after the latest updating of the map. This is the same as was used for the permit area analyses.

2) Rolling Hill Terrain

- a) There is an average (mean) of 94 dwellings within 5000' of the permit boundaries.
- b) There is an average (mean) of 87 dwellings within 5000' of the 2032' square placed within sections.

Given the difficulties inherent in making precise comparisons between permit areas and sections, the differences in the permit sections are not significant (N = 9 for flat terrain; N = 7 for rolling hill terrain).

PART THREE

LEGAL

Lawsuits and formal complaints to governmental regulatory agencies provide one set of indicators about issues and patterns of the impact of surface mine blasting.

It was recognized early in this study that a comprehensive legal and formal complaint analysis was not feasible. The absence of uniform reporting systems makes examination of state trial level cases difficult. A similar lack of uniform reporting systems for complaints is found across state regulatory agencies — and is compounded further by inadequacies in the data reported. Therefore, the legal and complaint research focused on state appellate and federal cases (using LEXIS as well as traditional legal research modes), state trial level cases in a sample of eight counties (in different states), and formal complaints in a sample of four counties (again in different states).

State appellate and federal cases appear to focus on three main issues of law: 1) strict liability vs. negligence; 2) measurement of appropriate amount of recovery; and 3) causation.

Analysis of state trial cases reveals a general lack of patterns in cases filed — and also a relatively small number of cases. Trends and patterns were also difficult to discern in complaints to state regulatory agencies — though here the inadequacies of available data make analysis even more difficult.

I. SURFACE COAL MINE LAW SUITS

It was recognized early in the study that there is no workable, comprehensive scheme available to find court records of all state trial level cases. In other words, it is not possible to cover effectively all state cases in all states. The only cases that are reported in any uniform system and are therefore available for comprehensive research include 1) state appellate level cases and 2) federal cases. This section will be divided into two parts. First, the methodology used and results of the research of these two types of cases will be discussed. Secondly, the methodology used and the results of the research of state trial level cases will be discussed.

1. State Appellate Level Cases and Federal Cases

In addition to more traditional modes of legal research, the LEXIS computer was used to cover the states of Arizona, Illinois, Kansas, Kentucky, Missouri, Ohio, Pennsylvania, and Virginia, as well as the federal blasting cases,¹ thereby suggesting that (although there were bound to be more trial level cases than the number of those cases ultimately appealed) litigation in this area is not very extensive (see Exhibit 1). Also it must be emphasized that the issues raised in these appellate cases are not entirely representative of the issues raised in trial level cases. In any event, the cases appeared to focus on three main issues.

*Since this chapter requires extensive foot notes and exhibits, these have been placed at the end of the discussion in numbered order.

The first issue to be noted is that of strict liability versus negligence, i.e., it is necessary for a plaintiff to show some kind of (even unintentional) wrongdoing on the part of the defendant blaster or is sufficient for the plaintiff to establish a causal link between the blasting and the alleged harm. Traditionally, wrongdoing on the part of the defendant was required. For example, in Republic Steel Corporation V. Peoples 217F.2d 236 (5th Cir. 1954), the court stated that:

The burden is on the plaintiffs to show some specific act or acts of negligence, and to show further that such negligence directly contributed to the result. Mere proof that the residential structures were damaged by blasting would not alone sustain the actions. It must further appear that the defendant company in using explosives, violated a duty owing by it to the plaintiffs in respect to their property or failed to exercise due care. Wrong and damage must concur to create a cause of action, Peoples at 238.

However, this view has been substantially eroded. It is now clear, as noted by the Missouri court, that "when one intentionally detonates explosives he is absolutely liable for injuries and damages which are the proximate result of such explosion," Donnell V. Quarries, Inc., 526S.W.2d 314, 316 (1975). The Illinois courts have provided a good illustration of the departure from the negligence standard:

One who makes use of an explosive in the ground near the property of another, when the natural and probable, though not inevitable, result of the explosion is injury to such property of the other, is liable for the resulting injury, however high a degree of care or skill may have been exercised in making use of the explosive; it is a matter of common knowledge that the use of dynamite as an explosive is intrinsically dangerous . . . it is not necessary that there have been negligence by the defendant . . . This is the majority view and is followed in Illinois, Peet V. Dolese and Shepard Co. 41 Ill. App. 2d 358, 368 (1963). See also Garland Coal and Mining Company v. Few, 207 F.2d 785, 789 (1959) and Caney Creek Coal Company v. Ellis, 437 S.W.2d 745, 748 (1969).

The second issue to be examined is that of measurement of the appropriate amount of recovery. Judgements awarded for structural damage will either be to cover the cost of repair or to compensate for the difference in the fair market value of a structure prior to and subsequent to blasting. The Missouri court, in upholding an award of \$27,000, stated that the "measure of damage to property in cases of explosion is the difference in market value of the property before and after the blasting operation or the cost of restoring the property whichever is the lesser amount," Donnell at 316-7. Similarly, the Kentucky court, while upholding a \$5,000 award, stated that "where a building cannot be reasonably repaired, the measure of damages is the fair market value just before and just after the injury," River Queen Coal Company, Inc. V. Mencer, 379 S.W.2d 461, 164 (1964). Also see

Kentucky Stone Company V. Gaddie, 396 S.W.2d 337, 340 (1965). These cases appear to be representative of the law on the subject. One case, however, seems to inexplicably depart from this mode of thinking. The Illinois court, in Aras V. Columbia Quarry Co., 367 N.E.2d 580 (1977), allowed a landowner, who had lost the water in his well, to recover the cost of drilling a new well even though that cost would apparently have exceeded the diminution in the value of the landowner's property.

It should also be noted that a plaintiff, seeking to recover profits allegedly lost due to blasting, must show that loss with "reasonable certainty," Caney Creek Coal Company at 749.

Finally, with respect to the measurement of the amount of recovery, in a nuisance case, it has been held that for a successful plaintiff "the proper measure of damages is the diminution in the value of the use of the property during the continuation of the nuisance" Nally and Gibson v. Mulholland, 399, S.W.2d 293, 294 (1966) (the plaintiff was awarded \$5,000 here).

The third issue to be examined is that of causation. Clearly, "it is necessary that there be a causal connection between the alleged damage and the blasting operation," Peet at 368. However, there appears to be no clear pattern from these appellate cases of what constitutes "causation," since "causation" is an issue of fact in each case and not an issue of law. Issues of fact are generally reserved for trial courts. Nevertheless, a few general principles emerge. First, damage to the property of plaintiff's neighbor may be admissible in court, Aras and River Queen Coal Company. Secondly, the testimony of expert witnesses is not necessarily dispositive of the causation issue, Ward v. H. B. Zachry Construction Company, 570 F.2d 892 (10th Cir. 1978). Finally, compliance with the federal regulations promulgated by the Office of Surface Mining would preclude liability of a defendant blaster in a civil suit.

It should be emphasized here that the foregoing cases were not sufficiently numerous to provide any detailed insight about patterns of blasting lawsuits. Instead, these cases serve to give an overview of the general kinds of issues that may be relevant at an appellate level. It must be clear, however, that the appellate level cases deal with questions of law, while the trial level cases (below) deal with questions of fact. Hence, the analysis above was concerned with gaining a degree of legal perspective and the analysis below will be more concerned with providing some insight into the numbers, patterns, and results of trial level cases.

2. State Trial Level Cases

As noted earlier, it was not possible to examine comprehensively blasting suits in all counties where blasting occurs (i.e., there is no uniform system of reporting). Hence, it was necessary to use a sampling method to gather legal data. In employing this sampling method, eight counties were selected for collection of legal data. These counties include: Walker County, Alabama; Wise County, Virginia; Preston County, West Virginia; Jefferson County, Ohio; Perry County, Kentucky; Indiana

County, Pennsylvania; Warrick County, Indiana; and Perry County, Illinois. Legal data was collected from each of these counties for a seven year period, i.e., 1972-1978. The methodology of this search will be discussed below, followed by a discussion of the results of the search.

The basic research method involved using a list of surface mines within a county and checking the mine companies in county defendant indices. Upon finding docket numbers for cases where these companies were sued, the files of these cases were checked and if the suits involved blasting all relevant information was ascertained. In effect, then, this method would ideally provide a complete list of all blasting cases where mining companies were sued. However, a few qualifications must be offered here.

The lists of coal companies checked in the county alphabetical defendant indices were procured from the 1978 Keystone Coal Manual⁴. Even if it is assumed that these are complete for 1977 mines, there will nevertheless be two unavoidable problems. First, companies formed in 1978 would not have been searched for in the indices. Secondly, companies which existed prior to 1977 but were no longer in existence in 1977 would not appear in these county lists. Hence, it is possible that a few cases (probably early in the seven year period) have fallen outside the scope of our methodology. However, this problem diminishes for research done for cases near the end of the period, i.e., reliability of data collected should be very high for the years 1976-1978.

It should also be noted here that it was assumed that cases were filed in the county where the blasting took place. Clearly, proper venue would exist in the county where the defendant does business or where the blasting created an alleged problem. It was deemed highly unlikely that a significant number of plaintiffs could have been able to (and would have chosen to) bring suit in a county outside the county where the blasting actually occurred.

Although it may be obvious, it should be pointed out that only those incidents that resulted in the actual filing of legal complaints could have been found in county indices. Clearly, there would be no record of threatened law suits or of settlements made prior to the formal institution of legal proceedings.

A final qualification concerns the results of cases settled after the initiation of law suits, i.e., subsequent to the filing of legal complaints. Although the terms of settlements in many of these cases were ascertained by phone calls made subsequent to an examination of incomplete court records, other terms were unavailable. Many of the plaintiffs were unreachable and some attorneys, viewing the settlements as confidential, refused to disclose the amounts of those settlements.

It is now possible to examine the results of the law suits in the eight counties over the seven year period. It seems useful to first note a few general findings. First, a total of 64 cases were filed during the period. 18 of the 64 cases, or 28.1% were found to be pending. Of the 46 completed cases, a high percentage, 82.6% (38 cases), were settled

before trial. The average (mean) settlement consisted of \$3,310.58.⁵ Only 7 of the 46 cases, or 15.2% actually went to trial. The plaintiffs recovered in each case that went to trial, with the average recovery being \$5,751.71. The average recovery for all complaints filed⁶ was \$3,715.97 (see Exhibit 2). One case was dismissed by plaintiff without prejudice.

More detailed analysis may be conducted by highlighting portions of Exhibits 2-17 . Therefore, each of these exhibits will be noted below.

Exhibit 2 - In addition to the general information discussed above, it can be seen that there is no clear yearly trend with respect to average settlements, verdicts, or results. Similarly, the percentage of cases that were settled or went to verdict showed no trend, although the percentage of settled cases remained quite high. The number of non-pending suits filed remained fairly constant, with the exception of a cluster of 1975 suits. When pending suits are added to our total of cases filed, the results are as follows: 1972 - 7 cases; 1973 - 4 cases; 1974 - 6 cases; 1975 - 17 cases; 1976 - 10 cases; 1977 - 9 cases; 1978 - 11 cases. Hence, the yearly number of suits has been greater for each of the last 4 years than of any of the 3 preceding years.

Exhibit 3 - 23 of 46 (76.4%) complaints filed were either within Walker County or Jefferson County. A high percentage of these cases were settled, with significantly higher average settlements in Walker County than in Jefferson County.

Exhibits 4, 5, 6 and 7 - In 16 of the 46 cases, property damage⁷ alone was the alleged harm. In the other 30 cases, both property damage and nuisance were alleged. Again, there appears to be no strong yearly trend in terms of the number of cases, the number of settled cases, the number of verdict cases, the average settlement, the average verdict, or the average result. However, one pattern which does emerge involves the higher percentage of settlements among suits where both property damage and nuisance are alleged (90.0%) vis a vis the percentage among suits where property damage alone is alleged (68.8%). Additionally, the average settlement for the former type of cases was higher. However, there was not a significant difference in the average result. No significant patterns emerged from state-by-state comparisons of the two types of cases (Exhibits 5 and 7).

Exhibits 8, 9, 10 and 11 - In 38 of the 46 cases (82.6%) vibration, alone, was claimed to be the cause of the alleged harm. In only 8 of the 46 cases (17.4%) were both vibration and flyrock claimed as the cause of the alleged harm. It is immediately apparent that 100% of the latter type of cases were settled out of court. Additionally, the average settlement (and therefore the average result in this instance) of \$4,500 is considerably higher than the average settlement (\$3,155.43) or average result (\$3,639.90) of vibration only cases. Of course, the settlement data on few cases involving both flyrock and vibration is limited. In state-by-state comparisons, it is interesting to note that for vibration cases (Exhibit 9), the average settlement (\$3,580.88) for Walker County was significantly higher than the average settlement (\$1,800.00) for Jefferson County. No other significant new patterns emerged from the state-by-state comparisons (Exhibits 9 and 11). It is useful to note that no flyrock cases were initiated in 1977 or 1978¹⁰ (Exhibit 10).

Exhibits 12, 13, 14 and 15 - The average amount sought per lawsuit was between \$19,000 - 20,000 for all lawsuits, for settled suits, and for verdict cases (Exhibit 12). This could indicate that the amount sought may not be a significant factor in whether or not a case is ultimately settled. It is also useful to note that the average amounts sought were greater for each of the final 3 years of the period than for any of the first 4 years of the period (Exhibit 12). It seems surprising that the amount sought in Walker County (\$15,380.95), although based on 21 cases, is considerably different than the average amount sought in Jefferson County (\$35,739.76), which also had a reasonable size sample of 10 cases (Exhibit 13). In any event, Jefferson County average recoveries were lower than those of any other county (Exhibit 13), and as was the percentage recovered of the amount sought, i.e., 5.0% (Exhibit 15). No other significant patterns appear to stem from Exhibits 12-15.

Exhibits 16 and 17 - It is noteworthy that 67.4% of the 46 completed law suits were filed against mining companies that each produced over 3 million tons of coal in 1977¹¹ ("Class 1" in Exhibit 16). Additionally, 73.7% of all settled cases involved Class 1 defendants; since this percentage is higher than the above mentioned 67.4%, it could indicate that large companies are more willing to settle cases than are smaller companies. Similarly, the fact that only 42.9% of all verdict cases are cases involving Class 1 defendants also supports this proposition. Exhibit 17 appears to offer no reliable pattern of variation in recovery by size of defendant.

Summary

Probably the most apparent finding from the above analysis is the general lack of patterns discernable from the cases filed. Although certain conclusions have been drawn, the relatively small number of cases filed often rendered comparisons between certain categories virtually useless. Nevertheless, the small number of cases (and the high percentage of settled cases) does seem to indicate that the blasting problem is not so troublesome that aggrieved parties are consistently forced to seek restitution through formal court proceedings.

II. COAL - FORMAL COMPLAINTS TO STATE AGENCIES

First, it must be noted that the availability of complaints data was not as great as had been hoped. For example, data was virtually un-¹²available from state agencies in Illinois, Indiana, Ohio and Alabama. Additionally, the Office of Surface Mining has been accepting complaints for only a very limited period of time. Hence, this analysis will be based on the available records from 4 counties, i.e., Preston County; West Virginia; Indiana County, Pennsylvania; Perry County, Kentucky; and Wise County, Virginia. 1977 and 1978 are the only 2 years for which data is available from all 4 counties. Hence, the Exhibits and this analysis will focus on those 2 years. Additionally, county exhibits have been included to note possible yearly trends for years prior to 1977 where complaints data is available. Again, it seems useful to conduct analysis by highlighting portions of exhibits, i.e., Exhibits 18-53.

Exhibits 18 and 19 - 117 complaints were filed in 1977 and 58 complaints were filed in 1978. Of these 175 complaints, 99 or 56.6% were filed in Wise County. The vast majority of all the complaints were based on vibration, i.e., 82.9%. Only 8.0% were based on flyrock and 9.1% of the complaints alleged both excessive vibration and flyrock. It is interesting to note that there were no complaints based on flyrock alone, filed in 1978.

Exhibits 20 and 21 - Agency responses to complaints were placed in 4 possible categories: 1) there was no response or the response was unclear, 2) some kind of investigation was made and there was no damage or violation found, 3) some kind of investigation was made and recommendations were made to the blasting company, or 4) a violation was found or citation was issued. Between 1977 and 1978, the percentage of complaints in category #1 rose from 21.4% to 32.8%. Similarly, the percentage of complaints in category #4 dropped from 23.9% to 15.5%. It is significant to note that, for the 2 year period, violations were found or citations were issued for only 21.1% of the complaints.

Exhibits 22 and 23 - It is clear that the majority of complaints (61.6%) were filed against the smallest companies (Exhibit 23), but it is interesting to note that only in Wise County are the majority of complaints (83.7%) against "#10" companies. Nevertheless, it is evident from Exhibits 22 and 23 that formal complaints against very large companies are quite rare, e.g.: only 2.3% of all complaints were filed against the two largest classes of mining companies.

Exhibits 24 - 29 - State Agency responses to vibration complaints appear to be quite similar to the responses to all complaints (see earlier discussion of Exhibits 20 and 21). However, one noticeable difference is that the percentage of cases, here, where a violation was found or a citation was issued is only 13.8% (Exhibit 25), while for all complaints, that percentage was 21.1% (Exhibit 21). Consistent with this finding, the percentage of flyrock complaints where a violation was found or a citation was issued was a high 78.6% (Exhibit 27) and the percentage of complaints alleging both vibration and flyrock where a violation was found or a citation was issued was 37.5% (Exhibit 29). Even though the numbers of complaints alleging flyrock or both vibration and flyrock were fairly small (14 and 16, from Exhibits 27 and 29), the disparity in these percentages seem to suggest that flyrock complaints (or complaints alleging both vibration and flyrock) are either more justified than vibration complaints or are more responsive to showings of improper blasting.

Exhibits 30 and 31 - A slight majority (51.4%) of the complaints were found to be based on annoyance allegations alone, while 30.9% were found to be based on property damage allegations and 17.7% were found to be based on both types of allegations (Exhibit 31). It is interesting to note, however, that property damage allegations represented 81.3% of all complaints in Preston County and 75.0% of all complaints in Indiana County. Comparable percentages in Perry County and Wise County were 29.2% and 18.2% respectively (Exhibit 31). The reasons for these differences are not clear.

Exhibits 32 - 37 - Surprisingly, there do not appear to be any significant patterns of varied agency response based on whether the complaints alleged annoyance, property damage, or both annoyance and property damage. In short, the percentage seen on Exhibits 33, 35 and 37 closely resembles the percentages of Exhibit 21.

Exhibits 38 and 39 - First of all, the vast majority of complaints (68.9%) were made by individuals who were within 2000 feet of the blast, (Exhibit 39). As expected, the greatest percentage of violations, or citations (30.8%) existed when the blasting was within 500 feet of the complainant.¹⁴ For 92.3% of the complaints where the blasting was within 500 feet, a violation was found (30.8%) or an investigation was conducted and no damage or violation was found (61.5%). In effect, then, State Agencies seemingly investigated and reported these complaints especially conscientiously.¹⁵ No other patterns clearly emerge from Exhibits 38 or 39.

Exhibits 40 and 41 - As noted in our discussion of Exhibits 22 and 23, most of the blasting complaints are filed against smaller mining companies. It is clear from Exhibit 41 that the percentage breakdown of agency response for smaller companies is very similar to the percentage breakdown of agency response for all companies, suggesting that the size of the blasting company may not have either a direct or indirect effect on the agency response. The percentages for the other 9 classes are either quite similar to the percentages for all companies (Class 3)¹⁶ or are based on a small number of complaints and, hence, fail to contradict the above proposition.

Exhibits 42 - 45 - In each of the 4 counties, vibration complaints represented a very large percentage of all complaints (see discussion of Exhibits 18 and 19). Few yearly trends appear in these exhibits, but two changes seem fairly apparent. First, Perry County's flyrock complaints dropped from 7 (24.1%) in 1977 to none in 1978. It should be noted, however, that this significant change was partially offset by the increase in complaints alleging both vibration and flyrock from 3.4% to 15.8% (Exhibit 44). Secondly, the large number of total complaints (68) registered in Wise County in 1977 vis a vis 1975, 1977 and 1978 is surprising (Exhibit 45). It is unclear why 47.2% of Wise County complaints over a 4 year period would occur in one year.

Exhibits 46 - 49 - It is interesting to note a high percentage of property complaints in Preston County (Exhibit 46) and Indiana County (Exhibit 47), as compared to a high percentage of annoyance complaints in Perry County (Exhibit 48) and Wise County (Exhibit 49). It is also surprising that, within Wise County, the percentage of annoyance complaints in both 1977 and 1978 were much higher than they were for either 1975 or 1976.

Exhibits 50 - 53 - It appears that there are no clearly significant yearly trends in agency response to complaints for any of our 4 counties. In terms of county comparisons, it is clear that Preston County and Indiana County had a higher percentage of complaints where no damages or violations were found, than did either Perry County or Wise County which both had higher percentages of complaints where violations were found or citations were issued than did either Preston County or Indiana County.

Summary

Again, as was the case with law suits, the relatively small amount of complaints data made trends and patterns somewhat difficult to discern. A major difference between the lack of legal data and the lack of complaints data, however, is the reason for this unavailability, i.e., there did not seem to be a significant number of law suits but the unavailability of much complaints data seemed to hinge on the fact that particular State Agencies did not provide adequate channels for the airing of citizens' complaints. In any event, the data from the 4 counties did allow for discerning of the various trends, patterns of the lack of trends and patterns which have been noted above.

III. QUARRIES - LAW SUITS AND FORMAL COMPLAINTS

Legal data and complaints data were collected from two different counties, i.e., Bucks County, Pennsylvania and Jefferson County, Kentucky. It must be noted here that data collected from these two counties was quite limited.

1. Law Suits

Bucks County - A list of 1976 quarries was procured from Pennsylvania's Annual Report on Mining, Oil and Gas, and Land Reclamation and Conservation Activities.¹⁷ The legal search technique was then conducted for the period, 1972 - early 1979. This search yielded one 1977 case where the plaintiff sought in excess of \$26,489.00. The legal complaint alleged that vibration had caused both property damage and nuisance (including physical injuries). This case, however, is still pending.¹⁸

Jefferson County - A list of 1978 quarries was procured from the head of the Division of Explosives of the Kentucky Department of Mines and Minerals. A legal search was then conducted for the period, 1972 - early 1979. Again, only one case was found, a 1974 case brought by the Kentucky Department of Mines and Minerals. The plaintiff sought an injunction after damage "to several automobiles and several commercial enterprises" was allegedly caused by flyrock and debris being thrown approximately 1500 feet. The case was settled in 1974.

Again, it is clear that within these two counties, blasting litigation does not appear to be very extensive. Apart from the fact that there is this dearth of law suits, no other conclusions can seemingly be drawn.

2. Formal Complaints

Bucks County - No formal complaints were received by the Department of Environmental Resources for 1976, 1977, or 1978. However, the Agency had apparently received numerous complaints (unavailable) which prompted it to issue restrictive permits to three quarry blasters.

Jefferson County - There were 15 formal complaints to the Kentucky Department of Mines and Minerals between 1973 and 1978. 4 of these complaints were filed in 1973, 3 in 1974, 1 in 1975, 2 in 1976, none in 1977, and 5 in 1978. Of the 15, 11 alleged excessive vibration and 4 alleged flyrock. 9 complaints alleged property damage, 4 alleged annoyance, and 2 alleged both property damage and annoyance. In all 15 cases, no violations were found (in 5 of these cases, recommendations were made to the blasting quarry), as seismographic measurements ranged from .0 inches/second to 1.7 inches/second. Therefore, it seems that the complaints records for Jefferson County were fairly informative and it is evident that all 15 recorded complaints were based on blasting that was found to be in compliance with state regulations (2 inches/second maximum peak particle velocity).

In summary, it appears from the quarry complaints data (and lack thereof) that in Bucks County and Jefferson County, blasting has been within the bounds of the law. However, although no violations were found, it was unfortunate that more data was unavailable in these counties to further strengthen the conclusion. Therefore, it is suggested that the terms of these permits, i.e., the blasting plans (phased during 1975), may serve as models for problem-avoidance. It must be emphasized here, though, that although complaints for these quarries stopped, there were also no complaints from blasting done by quarries not subject to similar restrictions.

FOOTNOTES

1. LEXIS was used to cover the following periods since 1965:

Arizona: Supreme Court, 1/65 - 6/78; Court of Appeals, 2/65 - 5/78.
Illinois: Supreme Court, 1/65 - 4/78; Appellate Court, 1/65 - 5/78.
Kansas: Supreme Court, 1/65 - 4/78; Court of Appeals, 1/77 - 3/78.
Kentucky: Supreme Court, 1/65 - 3/78; Court of Appeals, 1/76 - 4/78.
Missouri: Supreme and Appellate Courts, 1/65 - 5/78.
Ohio: Appellate Court, 1/65 - 12/77.
Pennsylvania: Supreme Court, 1/65 - 6/78; Superior Court, 1/65 - 4/78;
Commonwealth Court, 10/70 - 6/78.
Virginia: Supreme Court, 1/65 - 9/77.
Federal: U.S. Reports, 1/65 - 7/78; Court of Appeals, 1/65 - 7/78;
District Courts, 1/65 - 7/78.

2. (From Exhibit 1) These cases include:

Illinois: Aras v. Columbia Quarry Co., 367 N.E. 2d 580 (1977).
Kentucky: Kentucky Stone Company v. Gaddie, 396 S.W. 2d 337 (1965).
Nolly and Gibson v. Mulholland, 399 S.W. 2d 293 (1966).
Caney Creek Coal Company v. Ellis, 437 S.W. 2d 745 (1969).
Kentucky Stone Company v. Haney, 450 S.W. 2d 532 (1970).
Missouri: Donnell v. Vigus Quarries, Inc., 526 S.W. 2d 314 (1975).
Pennsylvania: DeFrank v. Sullivan Trail Coal Co., 425 Pa. 512 (1967).
Department of Environmental Resources v. Glasgow Quarry, Inc.,
351 A. 2d 689 (1976).
Virginia: Wells v. Whitaker, 207 Va. 616 (1966).

3. OSM's final regulations were issued March 13, 1979. Interim regulations withstood a challenge in the U.S. district Court for the District of Columbia (Master File No. 78-162, August 24, 1978).
4. 1978 Keystone Coal Industry Manual, McGraw-Hill (New York), 1978.
5. Derived from settlement figures available for 26 cases.
6. Excludes pending issues and cases settled for unknown quantities.
7. In many of the cases, the specific alleged damage was unascertainable. "Property damage" includes damage to houses, water supplies, trailers, or other property.
8. "Nuisance" complaints include complaints relating to nervousness, fear, sleeplessness, etc.
9. In only one of these eight cases, flyrock alone was claimed as the cause of the alleged harm. This case was grouped with the other seven cases which all claimed harm from both vibration and flyrock.

10. Additionally, no cases from 1977 or 1978 have alleged harm from flyrock.
11. "Classes" of coal companies by size (production) were determined with the use of a publication entitled U.S. Coal Production by Company, 1977, a Keystone Coal Industry Manual published by McGraw-Hill, (New York), 1978. The following list delineates the "class" categories by tonnage:

- Class 1 - 3,000,000 tons and more
- Class 2 - 2,000,000 - 2,999,999 tons
- Class 3 - 1,000,000 - 1,999,999 tons
- Class 4 - 700,000 - 999,999 tons
- Class 5 - 500,000 - 699,999 tons
- Class 6 - 400,000 - 499,999 tons
- Class 7 - 300,000 - 399,999 tons
- Class 8 - 200,000 - 299,999 tons
- Class 9 - 100,000 - 199,999 tons

For the analysis, Class 10 companies were those not listed in the Manual and assumed to be producers of less than 100,000 tons.

12. The Illinois Department of Mines and Minerals has been collecting blasting complaints since August, 1978 and only 3 complaints from Perry County had been registered as of March, 1979. In Indiana, the Division of Reclamation (of the Department of Natural Resources) has been accepting complaints since May, 1978 and have received no more than one complaint from Warrick County as of April, 1979. In Ohio, the Division of Mines (Industrial Relations) has been accepting complaints since 1975. However, no apparent procedure of information gathering is systematically employed and, as of March, 1979, 8 complaints had been recorded for the state and there were none from Jefferson County. In Alabama, the Surface Mining Reclamation Commission only began to accept complaints late in 1978.
13. This is a percentage based only on those complaints where the distances from the blast were available.
14. This excludes the 50% finding for complaints who were 3001 - 3500 from the blast since this 50% figure was only based on 2 complaints.
15. No other distance range equalled this 92.3% figure, except for the 3501 - 4000 range whose 100% figure was only based on 3 complaints.
16. The lack of complaints in the "recommendations made" category, for Class 3 companies, may well indicate an unwillingness of the part of the state agencies to make these recommendations to large companies (also see Classes 1, 2, 4, and 5 in this regard) or it may merely indicate a random departure from the norm in a small number of cases.
17. Annual Report on Mining, Oil and Gas, and Land Reclamation and Conservation Activities, Commonwealth of Pennsylvania, Department of Environmental Resources (Harrisburg), 1977.
18. Pending on April 26, 1979.

EXHIBIT 1
NUMBER OF APPELLATE LEVEL BLASTING CASES FOR SELECTED STATES²

STATE	1965-1974		1974-1978	
	HIGHEST STATE COURT	OTHER APPELLATE COURTS	HIGHEST STATE COURT	OTHER APPELLATE COURTS
ARIZONA	0	0	0	0
ILLINOIS	0	0	0	1
KANSAS	0	0	0	0
KENTUCKY	0	4	0	0
MISSOURI	0	0	0	1
OHIO	0	0	0	0
PENNSYLVANIA	0	1	0	1
VIRGINIA	1	0	0	0

EXHIBIT 2

Results of 1972-1978 Non-Pending Cases

Year	# of Cases	# Settled	% Settled	# of Settlement Values Available	Average Settlement	# to Verdict	% Verdict	Average Verdict	Average Result
1972	6	4	66.7	4	\$3375	2	33.3	2506	\$3085.33
1973	4	4	100	1	\$2400	0	0	-	\$2400
1974	6	5	83.3	2	\$1437.50	1	16.7	8500	\$3791.67
1975	17	16	94.1	13	\$4211.54	1	5.9	1250	\$4000
1976	7	6	85.7	5	\$2450	0	0	-	\$2450
1977	2	1	50	0	-	1	50	15,000	\$15,000.
1978	4	2	50	1	\$300	2	50	5250	\$1850
TOTAL	46	38	82.6	26	\$3310.58	7	15.2	5751.71	\$3715.79

EXHIBIT 3

Results of All Cases by State (Non-Pending)

County	# of Cases	# Settled	% Settled	% Settled	# of Settlement Values Available	Average Settlement	# to Verdict	% Verdict	Average Verdict	Average Result
Walker, Al.	21	19	90.5	90.5	19	3572.37	2	9.5	(2250) 1125	3339.29
Wise, Va.	1	1	100	100	0	-	0	0	-	-
Preston, W. Va.	5	2	40	40	0	-	3	60	(25,500) 8500	8500
Jefferson, Ohio	10	10	100	100	4	1800	0	0	-	1800
Perry, Ky.	4*	3	75	75	2	3750	0	0	-	3750
Indiana, Pa.	1	0	0	0	-	-	1	100	4012	4012
Warrick, Ind.	1	0	0	0	-	-	1	100	8500	8500
Perry, IL	3	3	100	100	1	3500	0	0	-	3500

* One case dismissed by plaintiff without prejudice.

EXHIBIT 4

Results of Property Damage (Only) Cases

Year	# of Cases	# Settled	% Settled	# of Settlement Values Available	Average Settlement	# to Verdict	% Verdict	Average Verdict	Average Result
1972	4	2	50%	2	4250	2	50%	(5012) 2506	3378
1973	4	4	100%	1	2400	0	0%	-	2400
1974	2	1	50%	1	2000	1	50%	8500	5250
1975	1	1	100%	1	900	0	0%	-	900
1976	3*	2	66.7%	2	3750	0	0%	-	3750
1977	1	0	0%	-	-	1	100%	15,000	15,000
1978	1	1	100%	1	300	0	0%	-	300
TOTAL	16	11	68.8%		2700	4	25%	7128	3854.77

*One case dismissed by plaintiff without prej.

EXHIBIT 5

Results of Property Damage (Only) Cases

County	# of Cases	# Settled	% Settled	# of Settlement Values Available	Average Settlement	# to Verdict	% Verdict	Average Verdict	Average Result
Walker, Al.	3	2	66.7	2	3700	1	33.3	1000	2800
Wise, Va.	1	1	100	0	-	0	0	-	-
Preston, W. Va.	1	0	0	-	-	1	100	15,000	15,000
Jefferson, Ohio	3	3	100	3	1066.67	0	0	-	1066.67
Perry, Ky	3*	2	66.7	2	3750	0	0	-	3750
Indiana, Pa.	1	0	0	-	-	1	100	4012	4012
Warrick, Ind.	1	0	0	-	-	1	100	8500	8500
Perry, Il.	3	3	100	1	3500	0	0	-	3500

* One case dismissed by plaintiff without prejudice.

EXHIBIT 6

Results of Cases Where Both Property Damage and Nuisance are Alleged

Year	# of Cases	# Settled	% Settled	# of Settlement Values Available	Average Settlement	# to Verdict	% Verdict	Average Verdict	Average Result
1972	2	2	100	2	2500	0	0	-	2500
1973	0	0	-	-	-	0	-	-	-
1974	4	4	100	1	875	0	0	-	875
1975	16	15	93.8	12	4487.50	1	6.3	1250	4238.46
1976	4	4	100	3	1583.33	0	0	-	1583.33
1977	1	1	100	0	-	0	0	-	-
1978	3	1	33.3	0	-	2	66.7	2 5250 (10,500)	5250
	30	27	90.0		3581.94	3	10	3916.67	3629.76

EXHIBIT 7

Results of Cases Where Both Property Damage and Nuisance are Alleged

County	# of Cases	# Settled	% Settled	# of Settlement Values Available	Average Settlement	# to Verdict	% Verdict	Average Verdict	Average Result
Walker, Al.	18	17	94.4	17	3557.35	1	5.6	1250	3429.17
Wise, Va.	0	0	-	-	-	0	-	-	-
Preston, W. Va.	4	2	50	0	-	2	50	(10,500) 5250	5250
Jefferson, Ohio	7	7	100	1	4000	0	0	-	4000
Perry, Ky.	1	1	100	0	-	0	0	-	-
Indiana, Pa.	0	0	-	-	-	0	-	-	-
Warrick, Ind.	0	0	-	-	-	0	-	-	-
Perry, IL.	0	0	-	-	-	0	-	-	-

EXHIBIT 8

Vibration Only Cases

Year	# of Cases	# Settled	% Settled	# of Settlement Values Available	Average Settlement	# to Verdict	% Verdict	Average Verdict	Average Result
1972	4	2	50	2	3250	2	50	2 2506 (5012)	2878
1973	3	3	100	1	2400	0	0	-	2400
1974	6	5	83.3	2	1437.50	1	16.7	8500	3791.67
1975	14	13	92.9	13	4211.54	1	7.1	1250	4000
1976	5*	4	80	4	1437.50	0	0	-	1437.50
1977	2	1	50	0	-	1	50	15,000	15,000
1978	4	2	50	1	300	2	50	2 5250 (10,500)	1850
TOTAL	38	30	78.9		3155.43	7	18.4	5751.71	3639.90

* One case dismissed by plaintiff without prejudice

EXHIBIT 9

Vibration Only Cases

County	# of Cases	# Settled	% Settled	# of Settlement Values Available	Average Settlement	# to Verdict	% Verdict	Average Verdict	Average Result
Walker, Al.	19	17	89.5	17	3580.88	2	10.5	2 1125 (2250)	3322.37
Wise, Va.	0	0	-	-	-	0	-	-	-
Preston, W. Va.	5	2	40	-	-	3	60	3 8500 (25,500)	8500
Jefferson, Ohio	7	7	100	4	1800	0	0	-	1800
Perry, Ky.	2*	1	50	1	1000	0	0	-	1000
Indiana, Pa.	1	0	0	-	-	1	100	4,012	4,012
Warrick, Ind.	1	0	0	-	-	1	100	8500	8500
Perry, IL.	3	3	100	1	3500	0	0	-	3500

* One case dismissed by plaintiff without prejudice.

EXHIBIT 10

Cases Where Vibration and Flyrock are Alleged

Year	# of Cases	# Settled	% Settled	# of Settlement Values Available	Average Settlement	# to Verdict	% Verdict	Average Verdict	Average Result
1972	2*	2	100	2	3500	0	0	-	3500
1973	1	1	100	0	-	0	-	-	-
1974	0	0	-	-	-	0	-	-	-
1975	3	3	100	0	-	-	-	-	-
1976	2	2	100	1	6500	0	0	-	6500
1977	0	0	-	-	-	0	-	-	-
1978	0	0	-	-	-	0	-	-	-
TOTAL	8	8	100		4500	0	0	-	4500

*In one of these cases, flyrock alone was alleged.

EXHIBIT 11

Cases Where Vibration and Flyrock are Alleged

County	# of Cases	# Settled	% Settled	# of Settlement Values Available	Average Settlement	# to Verdict	Verdict	Result
Walker, Al.	2*	2	100	2	3500	0	-	3500
Wise, Va.	1	1	100	0	-	0	-	-
Preston, W. Va.	0	0	-	-	-	0	-	-
Jefferson, Ohio	3	3	100	0	-	0	-	-
Perry, Ky.	2	2	100	1	6500	0	-	6500
Indiana, Pa.	0	0	-	-	-	0	-	-
Warrick, Ind.	0	0	-	-	-	0	-	-
Perry, IL.	0	0	-	-	-	0	-	-

*Flyrock only alleged in one case here.

EXHIBIT 12

Damages Sought (Non-Pending)

Year	Total Sought	Average Sought	Total Sought Settled Cases	Average Sought Settled Cases	Total Sought Verdict Cases	Average Sought Verdict Cases
1972	(6) 86,600	14,433.33	(4) 56,600	14,150	(2) 30,000	15,000
1973	(4) 6859.16	17,114.79	(4) 68459.16	17,114.79	0	-
1974	(6) 87909	14,651.50	(5) 78,409	15,681.80	(1) 9500	9500
1975	(17) 288,361.58	16,962.45	(16) 278,361.58	17,397.60	(1) 10,000	10,000
1976	(7)* 155,000	22,142.86	(6) 140,000	23,333.33	0	-
1977	(2) 80,000	40,000	(1) 50,000	50,000	(1) 30,000	30,000
1978	(4) 110,627	27,656.75	(2) 50,627	25,313.50	(2) 60,000	30,000
TOTAL	876,956.74	19,064.28	722,456.74	19,012.02	139,500	19,928.57

* One case dismissed by plaintiff without prejudice.

EXHIBIT 13

Damages Sought (Non-Pending)

County	Total Sought	Average Sought	Total Sought Settled Cases	Average Sought Settled Cases	Total Sought Verdict Cases	Average Sought Verdict Cases
Walker, Ala.	(21) 323,000	15,380.95	(19) 293,000	15,421.05	(2) 30,000	15,000
Wise, Va.	(1) 35,000	35,000	(1) 35,000	35,000	(0) 0	-
Preston, W.Va.	(5) 190,000	38,000	(2) 100,000	50,000	(3) 90,000	30,000
Jefferson, O.	(10) 357,397.58	35,739.58	(10) 357,397.58	35,739.76	(0) 0	-
Perry, Ky.	(4)* 125,000	31,250	(3) 110,000	36,666.67	(0) 0	-
Indiana, Pa.	(1) 10,000	10,000	(0) 0	-	(1) 10,000	10,000
Warrick, Ind.	(1) 9,500	9,500	(0) 0	-	(1) 9,500	9,500
Perry, Ill.	(3) 25,059.16	8,353.05	(3) 25,059.16	8,353.05	(0) 0	-

* One case dismissed by plaintiff without prejudice.

EXHIBIT 14

Damages Sought v. Amounts Recovered (See Exhibits 10 and 20)

Year	All Cases		Settled Cases		Verdict Cases	
	% Recovered of Amount Sought	% recovered of amount sought in all uses	% recovered of amount sought in settled cases	% recovered of amount sought in all cases	% recovered of amount sought in verdict cases	% recovered of amount sought in verdict cases
1972	21.4	23.4	23.9	17.4	16.7	
1973	14.0	14.0	14.0	-	-	
1974	25.9	9.8	9.2	58.0	89.5	
1975	23.6	24.8	24.2	7.4	12.5	
1976	11.1	11.1	10.5	-	-	
1977	37.5	-	-	37.5	50	
1978	6.7	1.1	1.2	19.0	17.5	
TOTAL	19.5	17.4	17.4	30.2	28.9	

EXHIBIT 15 (see Exhibits 3 and 13)

Damages Sought v. Amounts Recovered

County & State	All Cases		Settled Cases		Verdict Cases	
	% Recovered of Amount Sought	% Recovered of amount in all Cases	Recovered of amount Sought in Settled Cases	% recovered amount sought in all Cases	% recovered amount sought in Verdict Cases	% recovered of amount sought in Verdict Cases
Walker, Ala.	21.7	23.2	23.2	7.3	7.5	7.5
Wise, Va.	-	-	-	-	-	-
Preston, W.Va.	22.4	-	-	22.4	28.3	28.3
Jefferson, Ohio	5.0	5.0	5.0	-	-	-
Perry, Ky.	12.0	12.0	10.2	-	-	-
Indiana, Pa.	89.5	-	-	89.5	89.5	89.5
Perry, Ill.	41.9	41.9	41.9	-	-	-

EXHIBIT 16

Lawsuits by Size of Defendant

Class	All Cases			Settled Cases			Verdict Cases		
	# of Cases	% of Cases	# of Cases	% of Settled Cases	# of Settled Cases	# of Verdict Cases	% of Verdict Cases	# of Verdict Cases	
1	31	67.4	28	73.7	3	42.9			
2	0	0	0	0	0	0			
3	1	2.2	1	2.6	0	0			
4	1	2.2	1	2.6	0	0			
5	2	4.3	1	2.6	1	14.3			
6	1	2.2	1	2.6	0	0			
7	3	6.5	1	2.6	2	28.6			
8	3	6.5	3	7.9	0	0			
9	3*	6.5	1	2.6	1	14.3			
10	1	2.2	1	2.6	0	0			
TOTAL	46	-	38		7				

* Includes one case dismissed by plaintiff without prejudice.

EXHIBIT 17

Recovery by Size of Dependant

Class	Recovery Total	Recovery Average	Total Settled	Average Settled	Total Verdicts	Average Verdicts
1	82,025	(24)3417,71	71275	3394.05	10,750	(3)3583.33
2	0	-	0	-	0	-
3	-	-	-	-	0	-
4	-	-	-	-	0	-
5	5012	2506	1000	1000	4012	4012
6	-	-	-	-	0	-
7	22,500	11,250	-	-	22,500	11,250
8	8,800	2933.33	8,800	2933.33	0	-
9	3000	3000	-	-	3000	3000
10	5000	5000	5000	5000	0	-

EXHIBIT 18

1977-78 Coal Complaints

County	Complaints		Vibration Complaints		Flyrock Complaints		Complaints for both Vibration & Flyrock					
	1977	1978	1977	1978	1977	1978	1977	1978				
	#	%	#	%	#	%	#	%				
Preston, W.Va.	14	2	13	92.9	2	100	1	7.1	0	0	0	0
Indiana, Pa.	6	6	6	100	6	100	0	0	0	0	0	0
Perry, Ky.	29	19	21	72.4	16	84.2	7	24.1	0	0	1	3.4
Wise, Va.	68	31	54	79.4	27	87.1	6	8.8	0	0	8	11.8
TOTAL	117	58	94	80.3	51	87.9	14	12	0	0	9	7.7
												12.1

EXHIBIT 19

1977-78 Total Complaints

County, State	Complaints		Vibration Complaints		Flyrock Complaints		Vibration & Flyrock	
	#	%	#	%	#	%	#	%
Preston, W.Va.	16	9.1	15	93.8	1	6.3	0	0
Indiana, Pa.	12	6.9	12	100	0	0	0	0
Perry, Ky.	48	27.4	37	77.1	7	14.6	4	8.3
Wise, Va.	99	56.6	81	81.8	6	6.1	12	12.1
TOTAL	175	100.0	145	82.9	14	8.0	16	9.1

EXHIBIT 20

1977-78 Agency Response to Complaints

County	None or Unclear				No Damage or Violation Found				Recommendations Made				Violations Found or Citations Issued			
	1977		1978		1977		1978		1977		1978		1977		1978	
	#	%	#	%	#	%	#	%	#	%	#	%	#	%	#	%
Preston, W. Va.	2	14.3	1	50	9	64.3	1	50	1	7.1	0	0	2	14.3	0	0
Indiana, Pa.	0	0	1	16.7	6	100	4	66.7	0	-	0	0	0	-	1	16.7
Perry, Ky.	8	27.6	5	26.3	12	41.4	7	36.8	1	3.4	5	26.3	8	27.6	2	10.5
Wise, Va.	15	22.1	12	38.7	25	36.8	12	38.7	10	14.7	1	3.2	18	26.5	6	19.4
TOTAL	25	21.4	19	32.8	52	44.4	24	41.4	12	10.3	6	10.3	28	23.9	9	15.5

EXHIBIT 21

1977-78 Totals - Agency Response to Complaints

County	None or Unclear		No Damage or Violations Found		Recommendations Made		Violations Found or Citation Issued	
	#	%	#	%	#	%	#	%
Preston, W. Va.	3	18.8	10	62.5	1	6.3	2	12.5
Indiana, Pa.	1	8.3	10	83.3	0	0	1	8.3
Perry, Ky.	13	27.1	19	39.6	6	12.5	10	20.5
Wise, Va.	27	27.3	37	37.4	11	11.1	24	24.2
TOTAL	44	25.1	76	43.4	18	10.3	37	21.1

EXHIBIT 22

1977-78 - Size of Companies For Which Complaints Were Filed

	1	2	3	4	5	6	7	8	9	10
	77	77	77	77	77	77	77	77	77	77
	78	78	78	78	78	78	78	78	78	78
W. Va.	0	0	0	0	0	0	7	1	0	0
	0	0	0	0	0	0	0	0	0	0
Penn.	0	0	1	0	0	0	2	0	0	0
	0	0	0	0	0	0	1	1	0	0
Ky.	0	1	0	0	8	1	1	0	2	6
	0	0	0	0	0	0	2	1	0	4
Va.	2	0	0	0	9	3	0	0	0	1
	0	0	0	0	0	0	1	0	0	0
TOTAL	2	1	0	1	17	4	1	0	2	2
	2	1	0	1	17	4	1	0	2	2
	7	3	9	1	4	4	5	3	69	37
% of year's complaints	1.7	1.8	0	1.8	14.77	1.9	0	1.7	3.6	6.0
	1.8	14.77	1.9	0	1.7	3.6	6.0	5.4	7.8	1.5
	3.4	7.1	4.3	5.4	59.5	66.1				

EXHIBIT 23

1977-78 Totals - Size of Companies for Which Complaints Were Filed

County	#	%	#	%	#	%	#	%	#	%	#	%	#	%	#	%	Total				
Preston, W. Va.	0	0	0	0	0	0	0	0	8	50	0	0	0	0	1	6.3	7	43.8	16		
Indiana, Pa.	0	0	1	8.3	0	0	2	16.7	1	8.3	0	0	0	0	1	8.3	6	50	12		
Perry, Ky.	1	2.2	0	0	9	19.6	1	2.2	2	4.3	8	17.4	1	2.2	7	15.2	6	13	11	23.9	46
Wise, Va.	2	2.0	0	0	12	12.2	0	0	0	0	1	1	0	0	1	1	0	0	82	83.7	98
TOTAL	3	1.7	1	.6	21	12.2	1	.6	4	2.3	10	5.8	10	5.8	8	4.7	8	4.7	106	61.6	172

EXHIBIT 24

1977-78 Agency Response to Vibration Complaints

County	None or Unclear		No Damages or Violations Found		Recommendations Made		Violation Found or Citation Issued									
	1977	1978	1977	1978	1977	1978	1977	1978								
	#	%	#	%	#	%	#	%								
Preston, W.Va.	2	15.4	1	50	9	69.2	1	50	1	7.7	0	0				
Indiana, Pa.	0	0	1	16.7	6	100	4	66.7	0	0	0	1	16.7			
Perry, Ky.	8	38.1	5	31.3	9	42.9	6	37.5	1	4.8	5	31.3	3	14.3	0	0
Wise, Va.	13	24.1	12	44.4	22	40.7	11	40.7	7	13.0	1	3.7	12	22.2	3	11.1
TOTAL	23	24.5	19	37.3	46	48.9	22	43.1	9	9.6	6	11.8	16	17.0	4	7.8

EXHIBIT 25

1977-78 Totals - Agency Response to Vibration Complaints

County	Vibration Complaints		None or Unclear		No Damage or Violation Found		Recommendations Made		Violations Found or Citations Issued	
	#	%	#	%	#	%	#	%	#	%
Preston, W.Va.	15	10.3	3	20	10	66.7	1	6.1	1	6.7
Indiana, Pa.	12	8.3	1	8.3	10	83.3	0	0	1	8.3
Perry, Ky.	37	25.5	13	35.1	15	40.5	6	16.2	3	8.1
Wise, Va.	81	55.9	25	30.9	33	40.7	8	9.9	15	18.5
TOTAL	145	100	42	29.0	68	46.9	15	10.3	20	13.8

EXHIBIT 26.

1977-78 Agency Response to Flyrock Complaints

County	None or Unclear		1977		1978		1977		1978		1977		1978		1977		1978			
	#	%	#	%	#	%	#	%	#	%	#	%	#	%	#	%	#	%		
Preston, W.Va.	0	0	0	-	0	0	0	-	0	0	0	0	0	-	0	0	0	100	0	-
Indiana, Pa.	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-
Perry, Ky.	0	0	0	-	3	42.9	0	-	0	0	0	0	0	-	0	0	4	57.1	0	-
Wise, Va.	0	0	0	-	0	0	0	-	0	0	0	0	0	-	6	100	0	100	0	-
TOTAL	0	0	0	-	3	21.4	0	-	0	0	0	0	0	-	11	78.6	0	78.6	0	-

EXHIBIT 27

1977-78 Totals - Agency Response to Flyrock Complaints

County	Flyrock Complaints		None or Unclear		No Damage or Violation Found		Recommendations Made		Violations Found or Citations Issued	
	#	%	#	%	#	%	#	%	#	%
Preston, W.Va.	1	7.1	0	0	0	0	0	0	1	100
Indiana, Pa.	0	0	0	-	0	-	0	-	0	-
Perry, Ky.	7	50	0	0	3	42.9	0	0	4	57.1
Wise, Va.	6	42.9	0	0	0	0	0	0	6	100
TOTAL	14	100	0	0	3	21.4	0	0	11	78.6

EXHIBIT 28

1977-78 Agency Response to Complaints Alleging Both Vibration and Flyrock

County	None or Unclear		No Damages or Violations Found		Recommendations Made		Violation Found or Citation Issued	
	1977	1978	1977	1978	1977	1978	1977	1978
	#	%	#	%	#	%	#	%
Preston, W. Va.	0	-	0	-	0	-	0	-
Indiana, Pa.	0	-	0	-	0	-	0	-
Perry, Ky.	0	0	0	0	1	33.3	0	100
Wise, Va.	2	25	0	0	3	37.5	1	75.0
TOTAL	2	22.2	0	0	3	28.6	3	11.1

EXHIBIT 29

1977-78 Totals - Agency Response to Complaints Alleging Both Vibration and Flyrock

County	Vibration and Flyrock Complaints		None or Unclear		No Damage or Violation Found		Recommendations Made		Violations Found or Citations Issued	
	#	%	#	%	#	%	#	%	#	%
Preston, W.Va.	0	0	0	-	0	-	0	-	0	-
Indiana, Pa.	0	0	0	-	0	-	0	-	0	-
Perry, Ky.	4	25	0	0	1	25	0	0	3	75
Wise, Va.	12	75	2	16.7	4	33.3	3	25	3	25
TOTAL	16	100	2	12.5	5	31.3	3	18.8	6	37.5

EXHIBIT 30

1977-78 Harm Claimed

County	ANNOYANCE COMPLAINTS				PROPERTY COMPLAINTS				BOTH ANNOYANCE AND PROPERTY COMPLAINTS			
	1977		1978		1977		1978		1977		1978	
	#	%	#	%	#	%	#	%	#	%	#	%
Preston, W.Va.	2	14.3	1	50	12	85.7	1	50	0	0	0	0
Indiana, Pa.	0	0	1	16.7	4	66.7	5	83.3	2	33.3	0	0
Perry, Ky.	15	51.7	7	36.8	9	31.0	5	26.3	5	17.2	7	36.8
Wise, Va.	45	66.2	19	61.3	12	17.6	6	19.4	11	16.2	6	19.4
TOTAL	62	53.0	28	48.3	37	31.6	17	29.3	18	15.4	13	22.4

EXHIBIT 31

1977-78 - Harm Claimed

County	Complaints		Annoyance		Property		Both Annoyance and Property	
	#	%	#	%	#	%	#	%
Preston, W.Va.	16	9.1	3	18.8	13	81.3	0	0
Indiana, Pa.	12	6.9	1	8.3	9	75	2	16.7
Perry, Ky.	48	27.4	22	45.8	14	29.2	12	25
Wise, Va.	99	56.6	64	64.6	18	18.2	17	17.2
TOTAL	175	100	90	51.4	54	30.9	31	17.7

EXHIBIT 32

1977-78 Agency Response to Annoyance Complaints

County	None or Unclear		No Damages or Violations Found		Recommendations Made		Violation Found or Citation Issued	
	1977	1978	1977	1978	1977	1978	1977	1978
	#	%	#	%	#	%	#	%
Preston, W.Va.	0	0	1	50	1	100	0	0
Indiana, Pa.	0	-	0	-	0	0	0	100
Perry, Ky.	3	20.0	7	46.7	1	14.3	5	33.3
Wise, Va.	12	26.7	15	33.3	8	42.1	13	28.9
TOTAL	15	24.2	23	37.1	10	35.7	18	10.7

1
13
3
1

EXHIBIT 33

1977-78 - Agency Response to Annoyance Complaints

County	Annoyance Complaints		None or Unclear		No Damage or Violation Found		Recommendations Made		Violations Found or Citations Issued	
	#	%	#	%	#	%	#	%	#	%
Preston, W. Va.	3	3.3	0	0	2	66.7	1	33.3	0	0
Indiana, Pa.	1	1.1	0	0	0	0	0	0	1	100
Perry, Ky.	22	24.4	7	31.8	8	36.4	2	9.1	5	22.7
Wise, Va.	64	71.1	21	32.8	23	35.9	5	7.8	15	23.4
TOTAL	90	99.9	28	31.1	33	36.7	8	8.9	21	23.3

EXHIBIT 34

1977-78 Agency Response to Property Complaints

County	None or Unclear		No Damages or Violations Found		Recommendations Made		Violation Found or Citation Issued									
	1977	1978	1977	1978	1977	1978	1977	1978								
	#	%	#	%	#	%	#	%								
Preston, W.Va.	2	16.7	1	100	8	66.7	0	0	2	16.7	0	0				
Indiana, Pa.	0	0	1	20	4	100	4	80	0	0	0	0				
Perry, Ky.	2	22.2	0	0	4	44.4	3	60	0	2	40	3	33.3	0	0	
Wise, Va.	1	8.3	3	50	5	41.7	1	16.7	3	25	1	16.7	3	25	1	16.7
TOTAL	5	13.5	5	29.4	21	56.8	8	47.1	3	8.1	3	17.6	8	21.6	1	5.9

EXHIBIT 35

1977-78 - Agency Response to Property Complaints

County	Property Complaints		None or Unclear		No Damage or Violation Found		Recommendations Made		Violations Found or Citations Issued	
	#	%	#	%	#	%	#	%	#	%
Preston, W.Va.	13	24.1	3	23.1	8	61.5	0	0	2	15.4
Indiana, Pa.	9	16.7	1	11.1	8	88.9	0	0	0	0
Perry, Ky.	14	25.9	2	14.3	7	50	2	14.3	3	21.4
Wise, Va.	18	33.3	4	22.2	6	33.3	4	22.2	4	22.2
TOTAL	54	100	10	18.5	29	53.7	6	11.1	9	16.7

EXHIBIT 37

1977-78 - Agency Response to Both Annoyance and Property Complaints

County	Annoyance and Property Complaints		None or Unclear		No Damage or Violation Found		Recommendations Made		Violations Found or Citations Issued	
	#	%	#	%	#	%	#	%	#	%
Preston, W.Va.	0	0	0	-	0	-	0	-	0	-
Indiana, Pa.	2	6.5	0	0	2	100	0	0	0	0
Perry, Ky.	12	38.7	4	33.7	4	33.3	2	16.7	2	16.7
Wise, Va.	17	54.8	2	11.8	8	47.1	2	11.8	5	29.4
TOTAL	31	100	6	19.4	14	45.2	4	12.9	7	22.6

EXHIBIT 36

1977-78 Agency Response By Distance of Blast*

Distance	Complaints		None or Unclear		No Damage or Violations Found		Recommendations Made		Violation Found & Citation Issued											
	#	%	#	%	#	%	#	%	#	%										
0 - 500 ft.	6	9.5	7	25.9	1	16.7	0	0	0	0	1	16.7	3	42.9						
501 - 1000 ft.	11	17.5	9	33.3	1	9.1	4	44.4	7	63.6	4	44.4	1	9.1						
1001 - 1500 ft.	13	20.6	2	7.4	1	7.7	1	50	7	53.8	1	50	2	15.4						
1501 - 2000 ft.	11	17.5	3	11.1	5	45.5	1	33.3	5	45.5	1	33.3	0	0						
2001 - 2500 ft.	4	6.3	0	0	1	25.0	0	-	3	75	0	-	0	0						
2501 - 3000 ft.	7	11.1	3	11.1	2	28.6	2	66.7	2	28.6	0	0	1	14.3						
3001 - 3500 ft.	1	1.6	1	3.7	0	0	1	100	0	0	0	0	0	0						
3501 - 4000 ft.	2	3.2	1	3.7	0	0	0	0	2	100	1	100	0	0						
4001 - 4500 ft.	0	0	0	0	0	-	0	-	0	-	0	-	0	-						
4501 - -	8	12.7	1	3.7	2	25	0	0	2	25	1	100	2	25						
TOTAL	63	100	27	99.9	13	20.6	9	33.3	32	50.8	12	44.4	6	9.5	1	3.7	12	19.0	5	18.5

*Where blast distance is available.

EXHIBIT 39

1977-78 - Agency Response by Distance of Blast

Distance	Complaints		None or Unclear		No Damage or Violation Found		Recommendations Made		Violations Found or Citations Issued	
	#	%	#	%	#	%	#	%	#	%
0 - 500 ft.	13	14.4	1	7.7	8	61.5	0	0	4	30.8
501 - 1000 ft.	20	22.2	5	25.0	11	55.0	2	10	2	10
1001 - 1500 ft.	15	16.7	2	13.3	8	53.3	2	13.3	3	20.0
1501 - 2000 ft.	14	15.6	6	42.9	6	42.9	0	0	2	14.3
2001 - 2500 ft.	4	4.4	1	25.0	3	75.0	0	0	0	0
2501 - 3000 ft.	10	11.1	4	40	2	20	1	10	3	30
3001 - 3500 ft.	2	2.2	1	50	0	0	0	0	1	50
3501 - 4000 ft.	3	3.3	0	0	3	100	0	0	0	0
4001 - 4500 ft.	0	0	0	-	0	-	0	-	0	-
4501 - - -	9	10	2	22.2	3	33.3	2	22.2	2	22.2
TOTAL	90	99.9	22	24.4	44	48.9	7	7.8	17	18.9

EXHIBIT 40

1977-78 Agency Response by Size of Company

Class	Complaints		None or Unclear		No Damages or Violations Found		Recommendations Made		Violation Found or Citation Issued	
	1977	1978	1977	1978	1977	1978	1977	1978	1977	1978
1	2	1.7	1	100	0	0	0	0	0	0
2	0	0	0	0	0	1	100	0	0	0
3	17	14.7	4	23.5	9	52.9	1	25	0	4
4	1	9	0	0	0	0	0	0	1	100
5	2	1.7	2	0	2	100	0	0	0	0
6	7	6.0	3	14.3	5	71.4	1	33.3	0	0
7	9	7.8	1	0	8	88.9	0	0	0	0
8	4	3.4	4	0	1	25	2	50	0	3
9	5	4.3	3	40	2	40	2	66.7	0	1
10	69	59.5	37	24.6	23	33.3	15	40.5	19	27.5
TOTAL	116	100	56	22.4	50	43.1	24	42.9	28	24.1
			26		6		9		16.1	

EXHIBIT 41

1977-78 - Agency Response by Size of Company

Class	Complaints		None or Unclear		No Damage or Violation Found		Recommendations Made		Violations Found or Citations Issued	
	#	%	#	%	#	%	#	%	#	%
1	3	1.7	3	100	0	0	0	0	0	0
2	1	.6	0	0	1	100	0	0	0	0
3	21	12.2	5	23.8	10	47.6	0	0	6	28.6
4	1	.6	0	0	0	0	0	0	1	100
5	4	2.3	0	0	4	100	0	0	0	0
6	10	5.8	3	30	6	60	1	10	0	0
7	10	5.8	1	10	8	80	1	10	0	0
8	8	4.7	0	0	3	37.5	0	0	5	62.5
9	8	4.7	2	25	4	50	0	0	2	25
10	106	61.6	29	27.4	38	35.8	16	15.1	23	21.7
TOTAL	172		43	25.0	74	43.0	18	10.5	37	21.5

EXHIBIT 42

Preston County, West Virginia Complaints

Year	# of Complaints	Vibration Complaints #	Vibration Complaints %	Flyrock Complaints #	Flyrock Complaints %	Both Vibration & Flyrock Complaints #	Both Vibration & Flyrock Complaints %
1974	7	7	100	0	0	0	0
1975	3	3	100	0	0	0	0
1976	3	3	100	0	0	0	0
1977	14	13	92.9	1	7.1	0	0
1978	2	2	100	0	0	0	0
TOTAL	29	28	96.6	1	3.4	0	0

EXHIBIT 43

Indiana County, Pennsylvania Complaints

Year	# of Complaints	#	Vibration Complaints %	#	Flyrock Complaints %	#	Both Vibration & Flyrock Complaints %
1976	3	2	66.7	1	33.3	0	0
1977	6	6	100	0	0	0	0
1978	6	6	100	0	0	0	0
TOTAL	15	14	93.3	1	6.7	0	0

EXHIBIT 44

Perry County, Kentucky Complaints (See Exhibits 18 & 19)

Year	# of Complaints		Vibration Complaints		Flyrock Complaints		Both Vibration & Flyrock Complaints	
	#	%	#	%	#	%	#	%
1977	29	2.4	21	2.4	7	24.1	1	3.4
1978	19	84.2	16	84.2	0	0	3	11.8
TOTAL	48	77.1	37	77.1	7	14.6	4	8.3

EXHIBIT 4J

Wise County, Virginia - Complaints

Year	# of Complaints	Vibration Complaints #	Vibration Complaints %	Flyrock Complaints #	Flyrock Complaints %	Both Vibration & Flyrock Complaints #	Both Vibration & Flyrock Complaints %
1975	18	14	77.8	2	11.1	2	11.1
1976	27	20	74.1	6	22.2	1	3.7
1977	68	54	79.4	6	8.8	8	11.8
1978	31	27	87.1	0	0	4	12.9
TOTAL	144	115	79.9	14	9.7	15	10.4

EXHIBIT 46

Preston County, West Virginia Complaints

Year	Annoyance Complaints #	%	Property Complaints #	%	Both Annoyance & Flyrock Complaints #	%
1974	1	14.3	3	42.9	3	42.9
1975	0	0	1	33.3	2	66.7
1976	0	0	2	66.7	1	33.3
1977	2	14.3	12	85.7	0	0
1978	1	50	1	50	0	0
TOTAL	4	13.8	19	65.6	6	20.7

EXHIBIT 47

Indiana County, Pennsylvania Complaints

Year	Annoyance Complaints #	%	Property Complaints #	%	Both Annoyance & Flyrock Complaints #	%
1976	1	33.3	1	33.3	1	33.3
1977	0	0	4	66.7	2	33.3
1978	1	16.7	5	83.3	0	0
TOTAL	2	13.3	10	66.7	3	20

EXHIBIT 48 (See Exhibits 30 & 31)

Perry County, Kentucky Complaints

Year	Annoyance Complaints #	%	Property Complaints #	%	Both Annoyance & Flyrock Complaints #	%
1977	15	51.7	9	31.0	5	17.2
1978	7	36.8	5	26.3	7	36.8
TOTAL	22	45.8	14	29.2	12	25.0

EXHIBIT 49

Wise County, Virginia Complaints

Year	Annoyance Complaints #	%	Property Complaints #	%	Both Annoyance & Flyrock Complaints #	%
1975	3	16.7	6	33.3	9	50
1976	10	37.0	9	33.3	8	29.6
1977	45	66.2	12	17.6	11	16.2
1978	19	61.3	6	19.4	6	19.4
TOTAL	77	53.5	33	22.9	34	23.6

EXHIBIT 50

Preston County, West Virginia Complaints - Agency Response

Year	None or Unclear		No Damage or Violation Found		Recommendations Made		Violations Found or Citations Issued	
	#	%	#	%	#	%	#	%
1974	2	28.6	4	57.1	1	14.3	0	0
1975	0	0	2	66.7	1	33.3	0	0
1976	0	0	3	100	0	0	0	0
1977	2	14.3	9	64.3	1	7.1	2	14.3
1978	1	50	1	50	0	0	0	0
TOTAL	5	17.2	19	65.5	3	10.3	2	6.9

EXHIBIT 51

Indiana County, Pennsylvania Complaints - Agency Response

Year	None or Unclear		No Damage or Violation Found		Recommendations Made		Violations Found or Citations Issued	
	#	%	#	%	#	%	#	%
1976	2	66.7	0	0	1	33.3	0	0
1977	0	0	6	100	0	0	0	0
1978	0	16.7	4	66.7	0	0	1	16.7
TOTAL	3	20	10	66.7	1	6.7	1	6.7

EXHIBIT 52 (See Exhibits 20 & 21)

Perry County, Kentucky Complaints - Agency Response

Year	None or Unclear		No Damage or Violation Found		Recommendations Made		Violations Found or Citations Issued	
	#	%	#	%	#	%	#	%
1977	8	27.6	12	41.4	1	3.4	8	27.6
1978	5	26.3	7	36.8	5	26.3	2	10.4
TOTAL	13	27.1	19	39.6	6	12.5	10	20.8

EXHIBIT 53

Wise County, Virginia Complaints - Agency Response

Year	None or Unclear		No Damage or Violation Found		Recommendations Made		Violations Found or Citations Issued	
	#	%	#	%	#	%	#	%
1975	0	0	5	27.8	10	55.6	3	16.7
1976	2	7.4	16	59.3	2	7.4	7	25.9
1977	15	22.1	25	36.8	10	14.7	18	26.5
1978	12	38.7	12	38.7	1	3.2	6	19.4
TOTAL	29	20.1	58	40.3	23	16.0	34	23.6

PART FOUR

ANALYSIS OF BLASTING IMPACTS ON PROPERTY VALUES
AROUND A SELECTED SAMPLE OF QUARRIES

I. INTRODUCTION

The purpose of this analysis is to investigate the impact of quarry blasting on neighboring residences. Most economists agree that the best indicator of locational desirability is property value. With property value as an indicator, locational desirability can be translated into dollar terms. Property value will reflect any annoyance, risk, or general quality of living in its price tag. If there is a negative impact from quarry blasting, it should be evident in a decline in property values as the plots of land get closer to the quarry.

The characteristics making property values ideal indicators of desirability also cause the greatest hinderance to their implementation in research.

"Prices and rents do not exist in a vacuum. They are determined by the fluctuations in virtually every other element that influences demand and supply. The influence of these various elements varies from time to time and from community." 1

All other market forces are incorporated into property values. The critical task of this analysis is to try to isolate the impact of the quarry on property values and control for all other possible effects.

Quarries were selected because sites could be chosen which would have a relatively high residential density and would have long term site operations, characteristics needed for property value analysis. The analysis was designed to control potential non-blasting causes of variation in market value of homes. Homes were classified according to type of home, dollar value, and interval distances from the quarry sites. The quarries chosen represent differences in geographical location and size of urban population.

II. VARIABLES TO CONTROL

Table 1 is a list of possible influences on property values. The table is divided into two categories: structural variables and locational variables. Structural variables include: house size (floor area), age, construction material, occupancy, garage size, and lot size. These variables can be controlled by selecting a data sample that includes only single family residences and then developing housing categories that account for fluctuations in each variable (e.g.: recently built frame ranch with two-car garage). To control for lot size, houses such as the category above were chosen on only lots of $\frac{1}{2}$ acre and $\frac{1}{4}$ acre. In a given residential area surrounding a quarry, approximately four to six categories were developed for evaluation, based on site observations. Control for internal structural improvements (such as improved basements, panelling, modern appliances, etc) was not seen as a major requirement, nor would it have been possible within the constraints of this study. Structural variables were controlled

TABLE 1

CONDITIONS AFFECTING HOUSING COST

- A. Structural Variables
 - 1. Housing size
 - 2. Age of home
 - 3. Occupancy
 - 4. Lot size
 - 5. Construction materials
 - 6. Garage

- B. Locational Variables
 - 1. Neighborhood characteristics
 - a. Terrain
 - b. Street conditions
 - c. Racial mix
 - d. City limits
 - 2. Environmental conditions
 - a. Pollution
 - b. Quarry
 - c. Railroad
 - d. Manufacturing
 - 3. Accessibility
 - a. Central business district
 - b. Schools
 - c. Public transportation
 - d. Major highways
 - 4. Position in neighborhood
 - a. Next to busy street
 - b. Corner lot
 - c. Parks

by using housing categories based on a combination of observation and realtors' multiple listings division.

Locational variables can be controlled in two ways: 1) by omitting values that are influenced by other variables, and 2) by measuring the effect through the same process used to measure quarry impact, thereby identifying and separating them from the quarry impact. Many locational variables are inherently controlled due to the small sample area from which the data is obtained. The residential area surrounding a quarry is rarely more than a mile in diameter; most homes are the same distance (on any significant level) to the central business district or major highway, etc. The method by which each variable was controlled will be described in the specific quarry data analysis.

This process of isolating the quarry impact from other influences was done independently for each quarry location. The study itself was conducted in a case by case analysis.

III. SITE SELECTION

The counties and quarry locations were chosen from the Martin-Marrietta report on quarries (1974) which includes a map illustrating population and quarry densities by county. Most of the needed information is classified in tax assessment records, by county. Only counties with both a high concentration of quarries and population were considered as sites. Within this listing of high concentration counties, the selection was also based on geographic distribution and town size,

The exact location of the quarries in each county was determined from U.S.G.S. relief maps produced by state governments which are updated regularly. These indicate locations of towns, residential areas, manufacturing areas, railroads, highways, and quarries. Locating the quarries on these maps provides the information needed for town size, and residential proximity to quarries. The locations chosen are: Kansas City (Jackson County), Louisville (Jefferson County), Rockford (Winnebago County), Dupo (St. Clair County), Chicago (Cook County), and Philadelphia (Bucks County). This sample gives a wide range of town size and geographical distribution.

The map findings were validated by vibration consultants who monitor quarry blasting and therefore are familiar with exact locations of both active and inactive quarries, or by quarry companies in the region. When no consulting service was available in a region, a listing of mining companies by state was located in a commercial atlas or Pit and Quarry Directory. Contact with any mining company in the region produced information on location, ownership and activity of all quarries in that region.

IV. METHODOLOGY

If quarries are to have an impact on property values, homes in close proximity to a quarry should have a lower dollar value than homes of

similar structure at a greater distance, given that all other influences are controlled. The method used to test this hypothesis imposes a grid of equal distant gradients upon the U.S.G.S. map of a quarry, thus delineating the residences within each distance interval. These intervals are 500 feet, drawn to U.S.G.S. scale, which is approximately the width of a city block. As U.S.G.S. maps show sources of extraneous influences such as manufacturing, railroads and schools, their use is essential. With the aid of a city map, the names of the streets within each interval can be obtained.

Three sources of property value information in a community are: 1) tax assessments of property, 2) mortgage values of property obtained from community savings and loan companies, and 3) real estate listings from the multiple listing service. However, there are problems associated with each source. Multiple listing services are officially confidential and not for public use except for purchasing a home. Also, they are renewed either weekly, bi-weekly, or monthly depending on the service, and obsolete listings are disposed of. However, a realtor that carries multiple listings usually has a comparative price listing as well. This is a bi-yearly listing of homes sold, addresses, and prices from the beginning of the calendar year. From these two journals, currently sold homes, addresses, and descriptions can be obtained. This usually yields a fair amount of value if the region investigated is active in the market.

A less reliable source of property values is a mortgage bank. In a densely populated area there will often be many savings and loans institutions. Mortgages are confidential and addresses cannot be released, making it difficult to determine the grid in which the house lies. The value becomes even less reliable when entrusting the mortgage officer to place the home in one of the housing structure categories already formulated. Therefore, this source was omitted for all but one quarry site.

The most consistently reliable and abundant source of property values is from tax assessments. Given the U.S.G.S. map and the plotted grid of the quarry, the same area can be located on a tax assessor's index map. The index map shows an area as it is subdivided with lot sizes and street names. From these maps, index numbers for the individual residences surrounding the quarry at each distance interval can be obtained. These index numbers are listed numerically in the assessor's Platte books along with the corresponding value assessment. These assessments are usually a designated percentage of the market value.

Once the specific addresses, their values and locations in the gradient are determined, an additional value source such as a realtor listing is needed. Homes are categorized by addresses in multiple listing services, and can therefore be easily placed in their respective gradient and compared to the assessed valuation of similar property.

Once the two sets of values have been obtained, they can be fit into housing categories. Using the divisions given in retail descriptions, categories of property can be formulated by a visual examination of the region. The appearance of the home is judged, accounting for structural variables such as construction, size, age, and garage. Each property value, across all distance intervals, can be categorized in this manner. With the completion of this final step, the value, distance from quarry and house structure category for each plot of land can be determined.

V. DATA ANALYSIS

Initially property values and all housing variables must be averaged by housing category in all distance intervals. An average by category will show if similar types of homes change in value as the distance from the quarry increases. Also, it will lend information to the correlation of homes' prices and the effect of quarries (e.g.: whether lower rent houses are less suspect to quarry impact than higher priced houses). An average of the total number of values across housing categories within distance intervals will indicate whether proximity to a quarry has any effect on the type of housing that is built (e.g.: similar housing may not increase or decrease in value as distance from the quarry increases, but the type of home built closer to the quarry may be of lower quality).

The values used in the data analysis will be the tax assessments only. As can be seen from Table 2, assessed valuations were found to be far from the list or selling price in many instances. This clearly indicates that the assessed value is not an accurate indicator of list price. However, this study concentrates on examining the price differentials of similar homes in different locations which is a relative analysis. Since tax assessments are a more consistent and extensive data source than real estate listings, they are a more accurate indicator of relative changes. To combine realtor values in the average would distort the figures.

The following detailed composites provide the data compiled at each quarry site.

CASE 1: St. Clair County, Dupu, Illinois

Dupu was chosen as a sample of a small town. Two quarries were selected for analysis: Columbia and East St. Louis. The quarries are active and in close proximity to the residential centers.

A. Structural Variables

The housing categories formulated for both the Columbia quarry and East St. Louis quarry are as follows:

TABLE 2

A COMPARISON OF TAX ASSESSMENTS AND REALTOR SALE PRICES

House	Assessment	Realtor Sale Price
1	\$39,242	\$63,900
2	\$41,166	\$59,900
3	\$58,000	\$73,900
4	\$17,600	\$42,500
5	\$15,600	\$36,500
6	\$16,400	\$33,000
7	\$15,600	\$37,300

- (a) Bungalow - older frame structure (older than 5-10 years), no garage.
- (b) Slightly larger one story frame cottage (older than 5-10 years).
- (c) Frame or frame and brick one story ranch with carport or no garage, recently built.
- (d) Recently built (within 5-10 years) brick and frame ranch with enclosed garage.
- (e) Split level with attached enclosed garage, recently built.

All homes are on approximately the same sized plot of land.

B. Locational Variables

Locational variables were controlled in several ways. Neighborhood characteristics were controlled by the fact that conditions were the same for all residences. Street conditions, terrain, and racial mix were constant throughout the sample. The residences surrounding the Columbia quarry were all within the city limits and the residences surrounding the East St. Louis quarry were all outside the city limits (they do, however, receive city water). Therefore, there is no need for controlling the city limits effect on value; it would not be significant.

Since there is no manufacturing, the impact of the railroad was the only environmental condition assessed. A railroad line running north-south lies east of the Columbia quarry. Adjacent to both the railroad and the quarry is the residential area. To measure the railroad's impact, values of the homes between the railroad and the quarry were plotted by housing category as measured distance from the quarry. The homes adjacent to the railroad yet outside of the range of the quarry and independent of other variables were measured by distance from the railroad (Graph 1). Measured independently, the railroad had no consistent effect on the increase or decrease of property values. For the homes between the railroad and the quarry, it might be hypothesized that those most centralized between the two would have the highest property value. This was evident only in the case of the (c) type home. From the graph, it can be determined that the railroad has no significant impact on property values.

Accessibility to the central business district, schools, or public transportation was not a factor in property values due to the proximity of all homes to any destination listed above. There was only one school and all residences tested were within walking distance. No plots of land chosen for sample were on a busy street or corner lot so as to eliminate those possible effects.

With all other potential impacts controlled, the effect of the quarry itself could be independently measured (Graph 2, Graph 3).

If these graphs can be taken literally it seems as though lower rent housing such as categories (a) and (b) experience very little impact from the quarry as evidenced by fairly straight lines. However, in categories (c) and (d) there is evidence that the values increase as distance increases. It is not conclusive because category (c)'s slope drops at the last value, but the general slope could be significant. This is further warranted by Graph 3 which exhibits a declining home average value as distance increases from the quarry. We do note that the number of upper category homes is small.

CASE 2: Street Road Quarry: Bucks County, Philadelphia, Pennsylvania

Street Road quarry is located in a suburb of Philadelphia called Lower Southhampton. The quarry is located on the Philadelphia city limits, thereby classifying it as being in a densely populated metropolitan area.

A. Structural Variables

The housing categories at this site were categorized as follows:

- (a) Small frame medium aged cottage with no garage.
- (b) Frame ranch with carport.
- (c) Split level frame and brick construction with enclosed one car garage.
- (d) Raised ranch, frame and brick construction with enclosed two car garage.
- (e) Bi-level larger two story, mostly brick construction with two car garage.

B. Locational Variables

Other potential influences in the area were practically non-existent. All the homes were in a quiet wooded area, with equal accessibility to main thoroughfares, schools, and public transportation. All homes were within Lower Southhampton city limits. The highway running north-south adjacent to the quarry could have an impact, so the sample was restricted to homes off the road. Hence, all homes selected were subject to similar levels of highway noise. A comparison of property values for homes at increasing distant intervals from streets indicated no increase in cost. This further substantiates the minimal effect of the highway on values (Graph 5).

The quarry's effect independent of other influences had no consistent impact on the surrounding property values (Graph 4, Graph 5).

CASE 3: Materials Service Quarry: Cook County, Lyons, Illinois

The Materials Service quarry in Lyons (a suburb of Chicago) is another example of a quarry in a densely populated urban setting.

A. Structural Variables

The following housing categories were devised to control structural variables in this suburb of Chicago:

- (a) One story frame bungalow, no garage, aged.
- (b) One story frame ranch, carport, built within the last 20 years.
- (c) One story frame and brick larger sized ranch, carport-one car garage.
- (d) Split level frame and brick, one car garage.
- (e) Bi-level, larger sized frame and brick, two car garage.

With exception of category (a), all homes were built in relatively the same time period.

B. Locational Variables

All the homes are in the same neighborhood and share similar facilities (e.g.: streets, terrain, city limits). Heavy manufacturing exists south of the sample but all properties chosen (east and west) are parallel to that manufacturing area. None of the plots in the data sample rest on corner lots or busy streets, thereby eliminating that influence. Accessibility to schools and central business district are significantly equal.

As the distance increases from the quarry in a western direction, the property values show no increase (Graph 6), but in the eastern direction the property values increase slightly. Since they do not increase westwardly but do easterly, the increase is probably due to the forest preserve that lies 4500' to the east of the quarry. The closer the homes are to the preserve and its border river, the more desirable the homes become. This may show that a moderating variable such as a river bank or preserve has a greater effect on property values than a quarry. The average value of the homes decreases up to 1500' in both directions and begins an upward slope in costs as the property approaches a distance of 2500'; this is inexplicable.

CASE 4: Martin-Marietta Quarry: Jefferson County, Louisville, Kentucky

The quarry is located on the outskirts of Louisville in the suburb of Anchorage. The residences around the quarry consists of large plantation type homes ranging from $\frac{1}{2}$ acre plots to 10 acre plots. They are older,

larger homes, more-so than the average sample. This adds diversity to the sample but presents problems of consistency. There are not a large number of one, two, or five acre plots to compare by distance. The best results in the sample came from $\frac{1}{2}$ acre plots. In the $\frac{1}{2}$ acre category there is no indication of any consistent correlation between distance and values (Graph 8). There does seem to be a correlation between types of homes built and proximity to the quarry (Graph 9).

No other significant variables existed in the sample. The terrain was constant and it was an area of minimal development.

CASE 5: Blacktop Quarry: Winnebago County, Rockford, Illinois

The Blacktop Quarry is within the Rockford city limits. This constitutes a quarry location in a medium level of population and in a small urban center. However, the residences surrounding the quarry were in fairly close proximity to each other.

A. Structural Variables

The following housing categories were devised to control structural variables for the Blacktop Quarry:

- (a) One story frame bungalow, no garage, aged.
- (b) Two story bungalow, separate garage.
- (c) Recently built (within 10 years) ranch, frame and brick.
- (d) Ranch, mostly brick construction, attached two car garage.
- (e) Bi-level, two car garage.

B. Locational Variables

All of the neighborhood characteristics had a consistent effect on the home values, so they would have no relative effect on prices except for the terrain of the northern sample which was wooded. This may have increased the homes' values relative to the western or eastern homes as indicated on Graph 10. In general, however, property values in all three directions consistently increase as distance from the quarry increases. The high cost homes (categories (c) and (d)) exhibit more of an increase than the lower cost home (b). This was also evident in the Dupo quarries.

CASE 6: 63rd and Route 50 Quarry, Jackson County, Kansas City, Missouri

The 63rd and Route 50 quarry is located in the metropolitan area of Kansas City just outside of the city limits. It could be classified as a fairly densely populated suburb.

A. Structural Variables

The housing categories at this site were figured as follows:

- (a) Small frame ranch with no garage.
- (b) Larger ranch, frame and brick, carport or separate garage.
- (c) Split level, frame with one-two car garage.
- (d) Larger split level, brick and frame, two car garage.
- (e) Large two story, mostly brick, two car garage, built within last 5 years.

B. Locational Variables

The neighborhood terrain and street conditions were constant for all homes. The neighborhood is mixed racially which would affect the resale value of the homes only relatively in respect to other areas, not in respect to other homes within the neighborhood. The accessibility to the central business district and major highways are equal and no lots on a busy street or corner lot were chosen.

Graph 12 indicates that all categories of homes east of the quarry increased in cost as distance increased. High cost residences to the north of the quarry rose in value while lower cost homes declined in value. East of the quarry, the average cost of all the homes rose as the distance from the quarry increased. This may be due to the fact that the expressway runs north-south adjacent to the quarry. The homes north of the quarry run parallel to the expressway. The highway impact could be greater than the quarry impact thereby causing the inconsistent and horizontal results in Graph 12 for the northern homes. The homes east of the quarry exhibit very conclusive findings to support the hypothesis that quarries have an effect on property values.

CASE 7: Holmes and Bannister Quarry: Jackson County, Kansas City, Mo.

This quarry is inside the Kansas City limits in a densely populated urban area.

A. Structural Variables

- (a) Frame ranch, aged, no garage.
- (b) Recently built (within 10 years), ranch, no garage.
- (c) Split level, brick and frame, two car garage.
- (d) Bi-level, recently built (within 10 years), brick and frame, two car garage.
- (e) Large new bi-level, recently built (within 5 years), brick and frame, two car garage.

B. Locational Variables

No manufacturing exists in the area and all the homes are within Kansas

City limits and schools. No values were chosen from busy streets or corner lots.

Graphs 14 and 15 exhibit the most conclusive findings of the entire quarry sample. Averaged by category, almost all values increased as distance from the quarry increased. Categories (a) and (b) to the west of the quarry decline from 1000' - 1500', but this could be due to the proximity of the divided highway 2500' to the west or the creek that runs next to it. The average value of all homes in both directions increases as distance from the quarry increases.

VI. CONCLUSIONS

The market for housing is by nature a local market. Competition for homes occurs strictly within towns or metropolitan areas, and because of this, broad conclusions or national averages about a quarry's impact are difficult to make. Influences will have varying effects from community to community. In the findings given, this seems to be the case. For example, at the Kansas City site the findings suggest a possible impact of quarries on property values, while at the Philadelphia site property values were inversely related to distance from the quarry.

If a conclusion can be reached from the graphs, it would have to be that blasting quarries do not have a significant effect on property values. Even when housing costs increased over distance, the slope was very gradual on the average. The presence of a quarry in a community, given the findings of this analysis, does not represent much of a cost to the community. When analyzed from the perspective of cost of homes in relation to the distance from a quarry, average cost of homes 500' away was not significantly different from homes 2500' away (Graph 16).

In summary, this analysis finds no consistent relationship between quarries and property values, a finding which suggests that other variables tend to be the dominant determinants of property values. It may be noted that local realtors interviewed during the field research tended to reach the same basic conclusion, i.e., that "quarries may have an impact on housing costs, but if they do, it is minimal compared to all other influences that affect the desirability of a home."

FOOTNOTES

1. Beyer, Glenn H., Housing and Society, McMillan: New York, 1967, p. 133

SUMMARY OF PROPERTY VALUE STUDY

<u>Quarry Site</u>	<u>Characteristic</u>	<u>Impact of Proximity to Quarry on Property Values</u>
1. Dupu St. Clair County Illinois	Small town	a) Insignificant impact on lower value homes b) Some evidence of impact on higher value homes
2. Lower Southhampton Bucks County Pennsylvania	Densely populated metropolitan area (suburb of Philadelphia)	No consistent impact
3. Lyons Cook County Illinois	Densely populated metropolitan area (suburb of Chicago)	Mixed findings. Up to 1500 feet, property values decline. Between 1500-2500, property values increase.
4. Anchorage Jefferson County Kentucky	Suburb of Louisville	a) No consistent correlation between distance property value b) Moderate correlation between distance and type of house
5. Rockford Winnebago County Illinois	Medium level of popula- tion in smaller urban center	Increase in value correlates with increase in distance, but more so for higher than for lower value homes.
6. Jackson County Missouri	Moderately densely populated suburb (suburb of Kansas City)	a) East of quarry -- value increase correlates with distance increase b) North of quarry -- higher cost homes increase but lower cost homes decrease in value as distance from quarry increases c) Inconsistency may reflect impact of highway more than quarry.
7. Kansas City Jackson County Missouri	Densely populated urban area	a) Generally, values increase as distance increases. b) However, lower cost homes west of quarry decline in value from 1000 to 1500 feet. c) Inconsistency may reflect impact of highway more than quarry.

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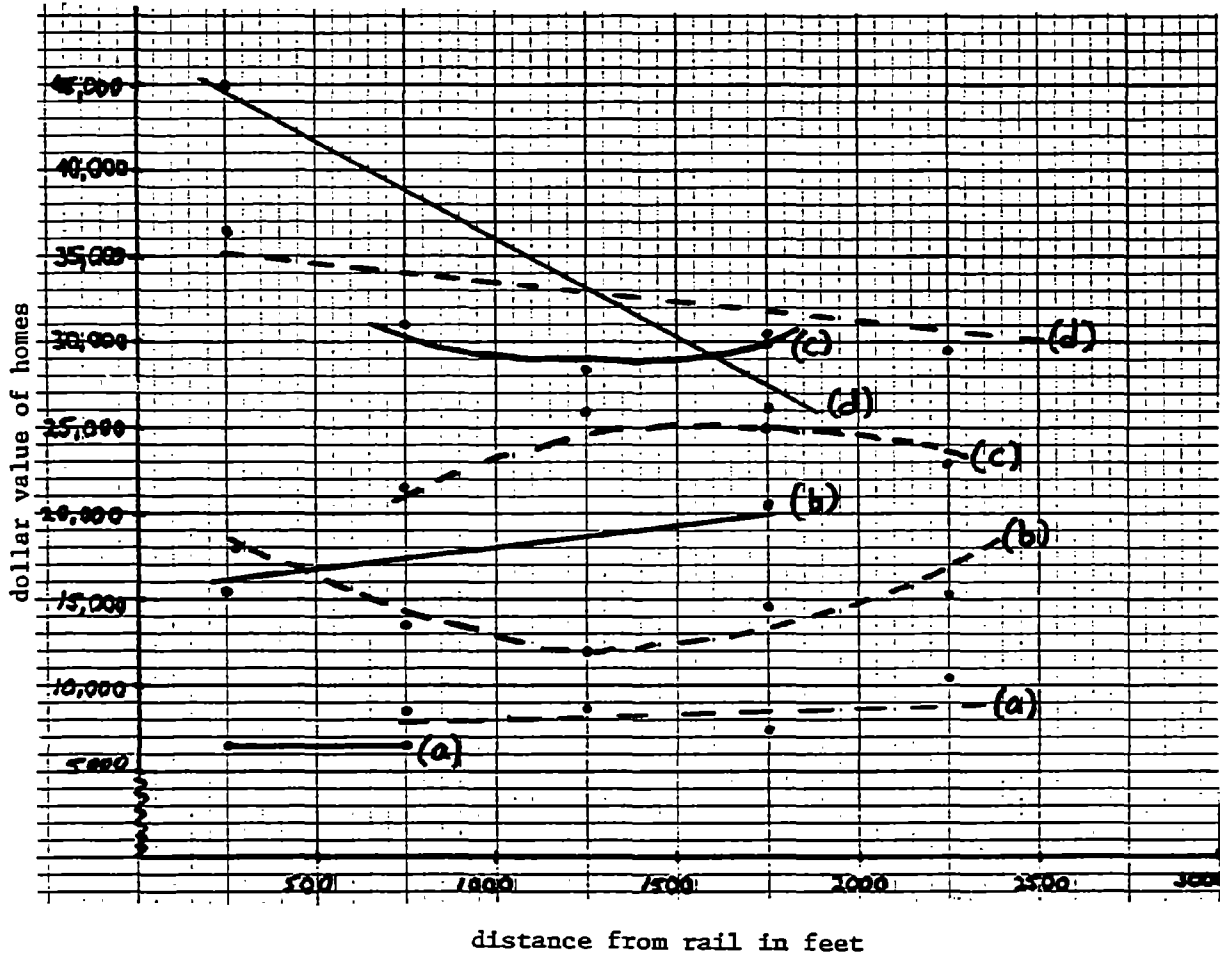
Columbian
Map of Oregon

Illustration #1

GRAPH 1

DUPO QUARRIES

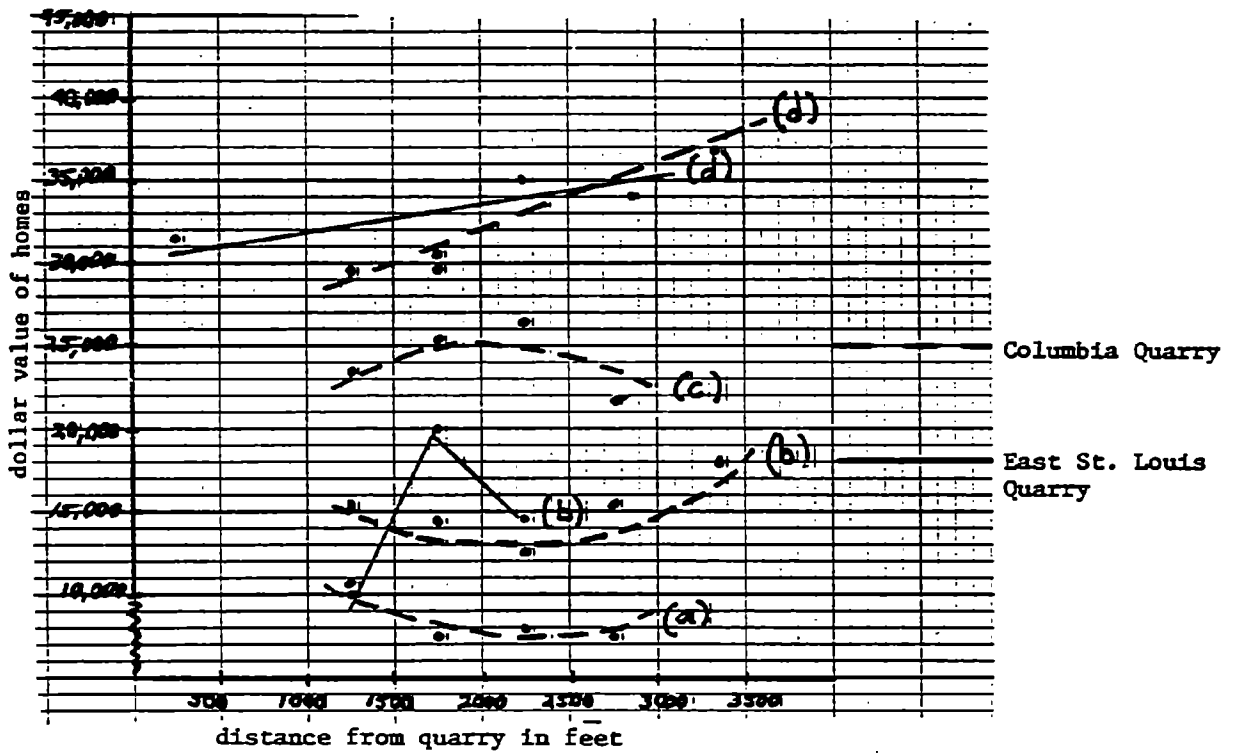
Railroad Impact on Housing Values



Values by housing category of homes between rail and quarry as measured by distance from rail

Values by housing category of homes in-town measured by distance from rail

GRAPH 2 - Values of Each Category of Homes by Distance from Quarry
(Dupo Quarries)



GRAPH 3 - Values of All Homes by Distance from Quarry

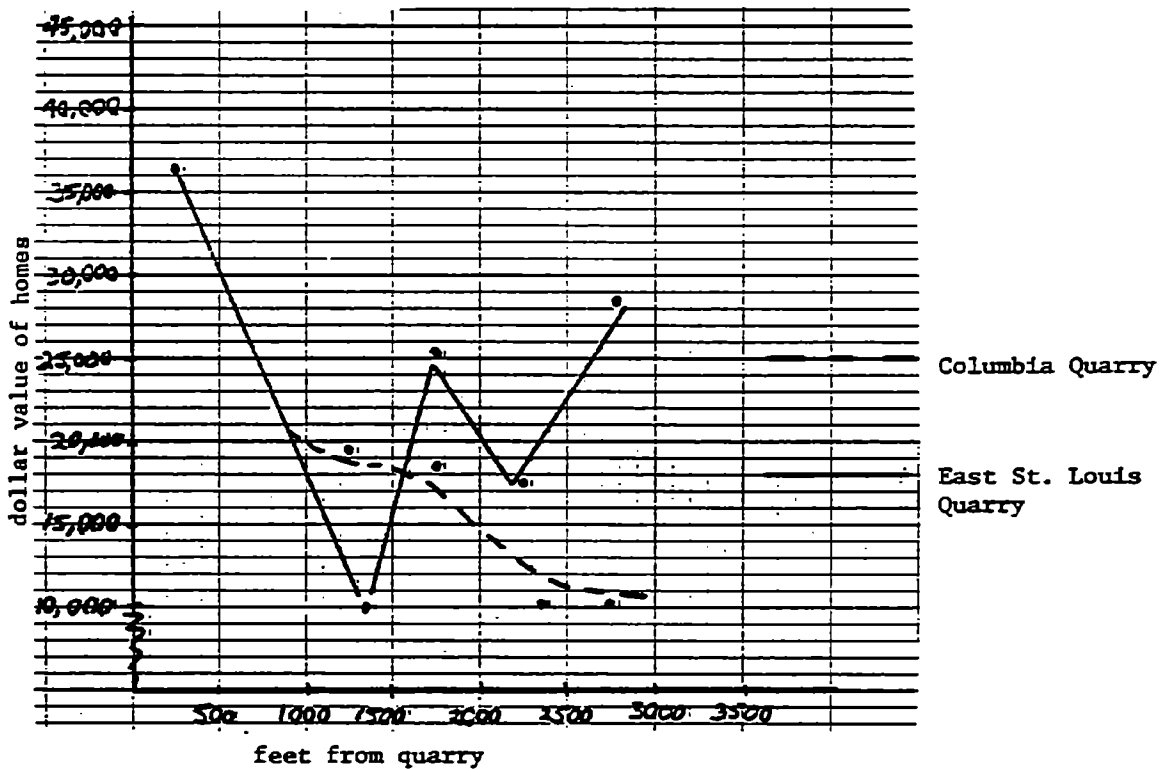


TABLE OF AVERAGE HOUSING VALUES

ST. CLAIR COUNTY, DUPO, ILLINOIS

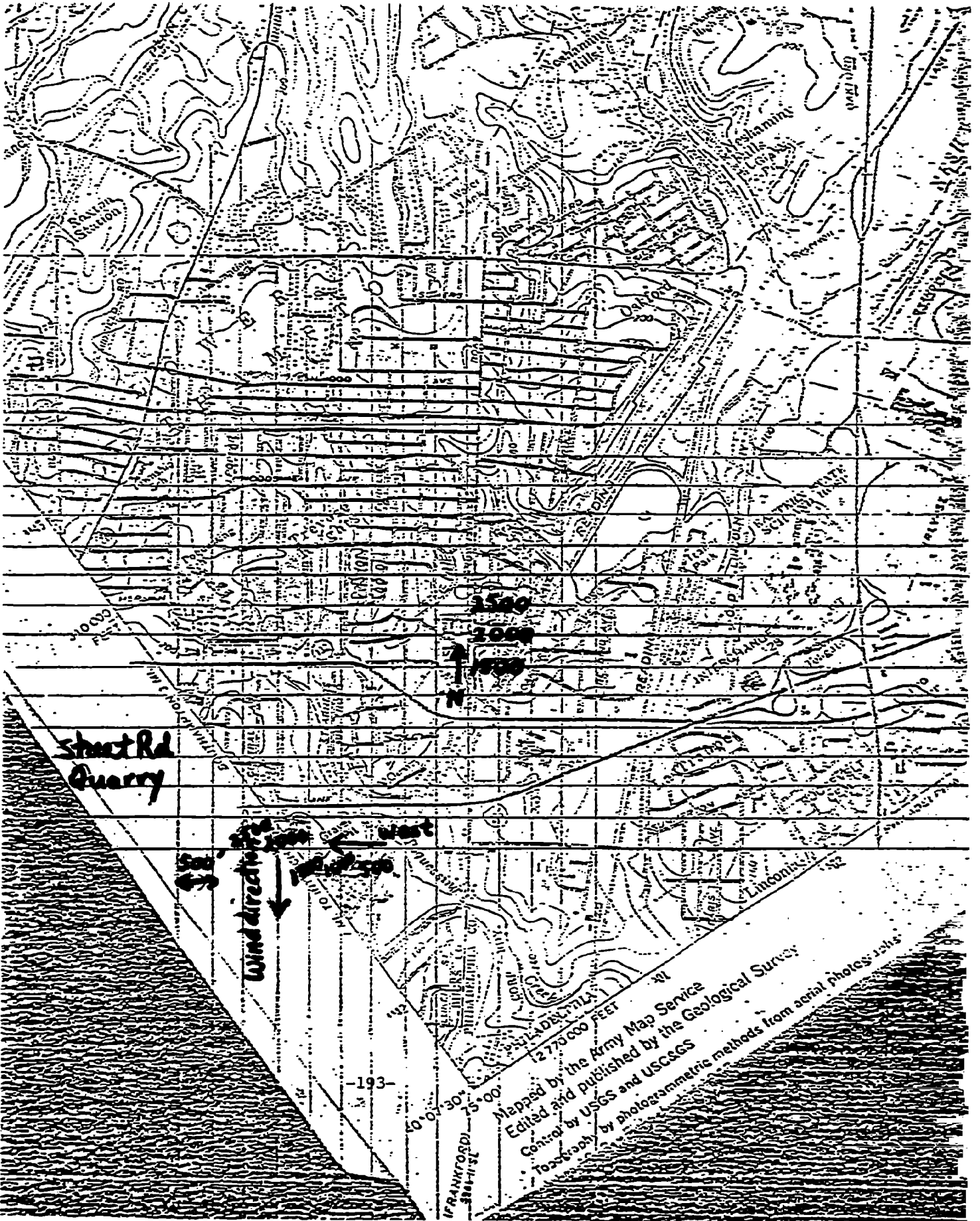
COLUMBIA QUARRY

Direction from quarry	Housing type	Distance from quarry (in feet)					
		0-500	500-1000	1000-1500	1500-2000	2000-2500	2500-3000
East	(a)	-	-	10,329	7188	7935	7198
	(b)	-	-	15,111	14,951	12,507	15,029
	(c)	-	-	23,912	25,480	26,043	21,996
	(d)	-	-	29,697	30,921	-	-
	(e)	-	-	-	43,462	-	-

EAST ST. LOUIS QUARRY

East	(a)	-	-	-	-	5000	-
	(b)	-	-	10,000	20,000	15,500	-
	(c)	-	-	-	25,667	-	23,000
	(d)	31,750	-	-	30,000	35,000	34,000
	(e)	45,000	-	-	-	-	-

ALL HOME AVERAGE	0-500	500-1000	1000-1500	1500-2000	2000-2500	2500-3000
Columbia quarry	-	-	19,193	18,696	10,464	10,099
E. St. Louis	36,166	-	10,000	25,400	17,750	28,500



Sheet Rd
Quarry

Wind direction
↓

N 100
100

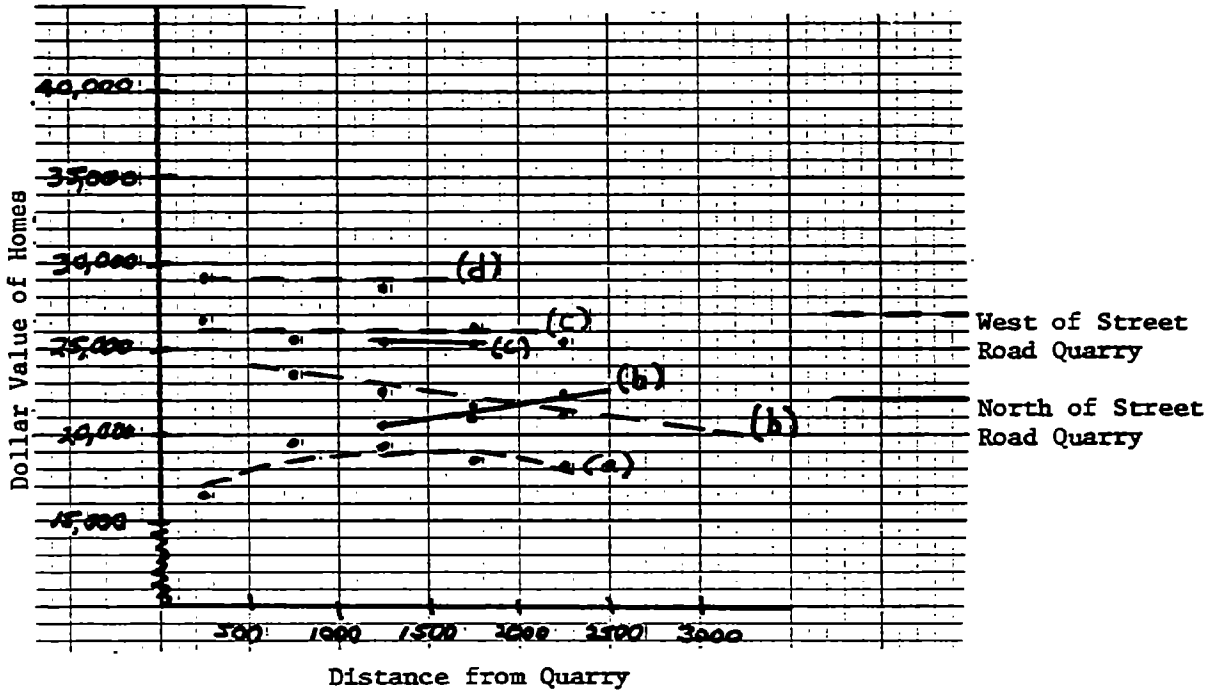
Mapped by the Army Map Service
Edited and published by the Geological Survey
Control by USGS and USC&GS
Topography by photogrammetric methods from aerial photographs
12770 000 FEET

-193-

Street Road Quarry

GRAPH 4

Average Housing Values By Category Measured Distance from Quarry



GRAPH 5

Average of All Housing Values by Distance from Quarry
($\frac{1}{2}$ acre + $\frac{1}{2}$ acre plots)

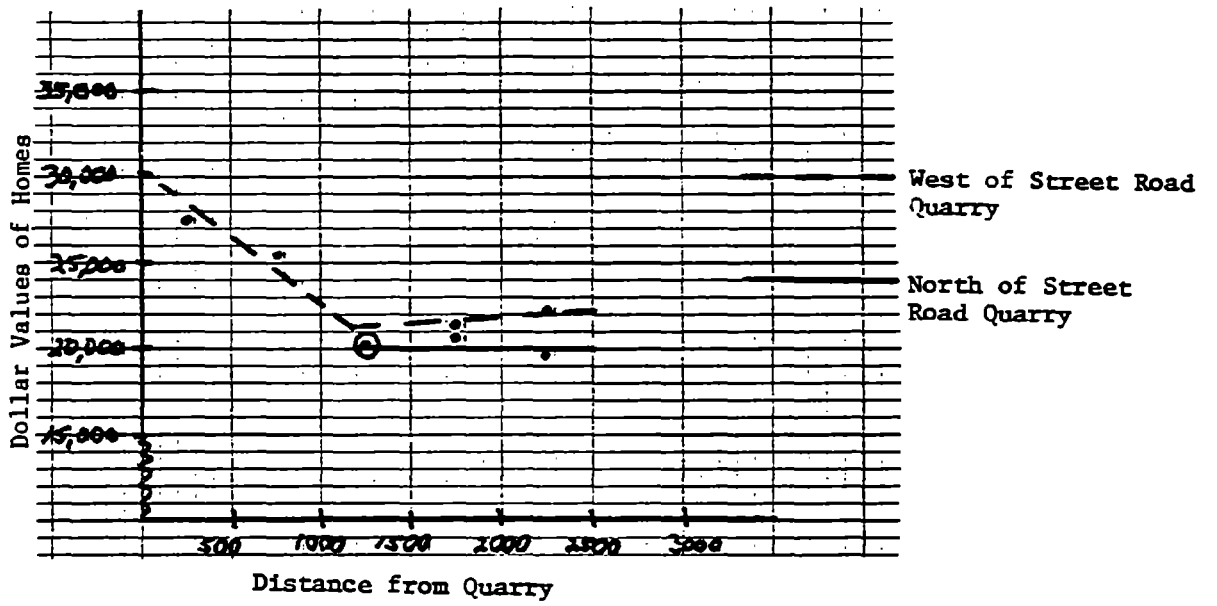
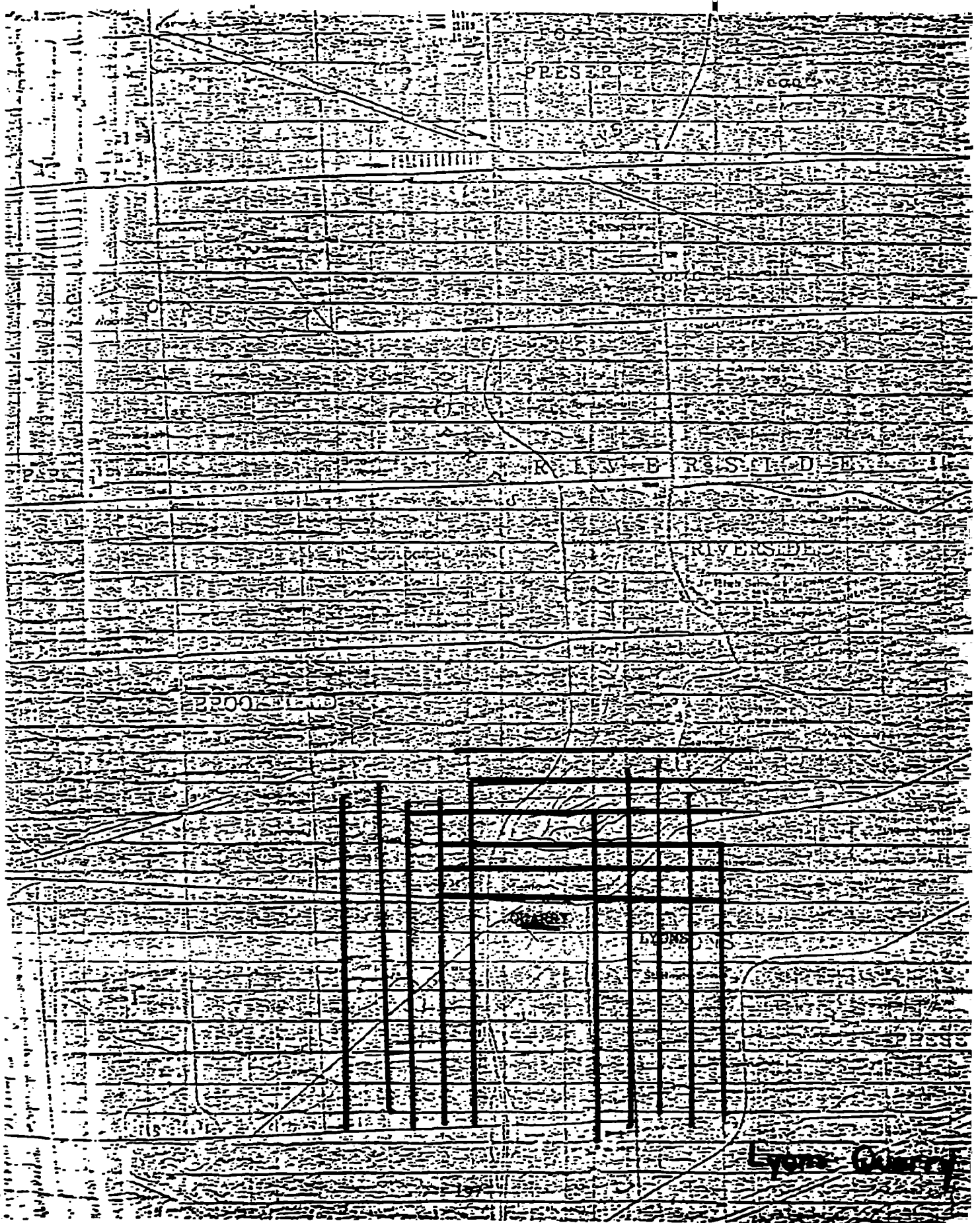


TABLE OF AVERAGE HOUSING VALUES

STREET ROAD QUARRY, BUCKS COUNTY, PHILADELPHIA, PENNSYLVANIA

Direction from quarry	Housing type	Distance from quarry (in feet)					
		0-500	500-1000	1000-1500	1500-2000	2000-2500	2500-3000
North	$\frac{1}{4}$ acre						
	(a)	-	-	18,550	18,504	18,104	-
	(b)	-	-	21,200	21,640	23,133	-
	(c)	-	-	-	-	-	-
	$\frac{1}{2}$ acre	-	-	-	-	-	-
	(a)	-	-	18,400	18,400	18,000	-
	(b)	-	-	20,800	21,257	21,800	-
	(c)	-	-	25,800	25,000	-	-
	(d)	-	-	-	30,200	-	-
	West	$\frac{1}{4}$ acre					
(a)		-	-	-	-	-	-
(b)		-	-	-	-	-	-
(c)		24,876	25,314	-	-	-	-
(d)		29,280	28,666	-	-	-	-
(e)		31,300	32,000	-	-	-	-
$\frac{1}{2}$ acre							
(a)		16,800	19,600	19,200	18,560	18,400	-
(b)		-	23,000	22,400	21,866	21,750	-
(c)		26,900	25,600	-	26,200	25,800	-
(d)	29,000	-	28,400	-	-	-	
(e)	32,050	-	-	-	-	-	
<u>ALL HOME AVERAGE</u>							
North		-	-	20,030	21,704	19,427	-
West		27,629	25,858	20,153	21,452	22,181	-

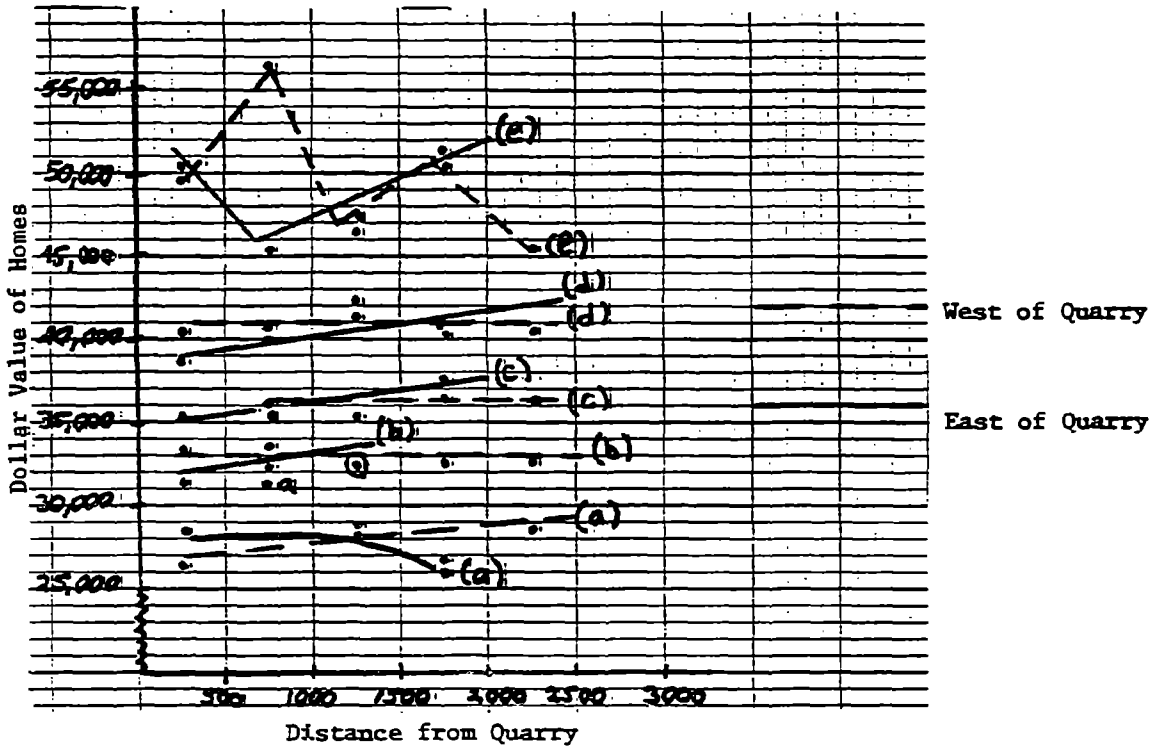


Material Service Quarry

GRAPH 6

Average Housing Values by Category Measured Distance from Quarry

(All Same Sized Plots)



GRAPH 7

Average of All Housing Values by Distance from Quarry

(All Same Sized Plots)

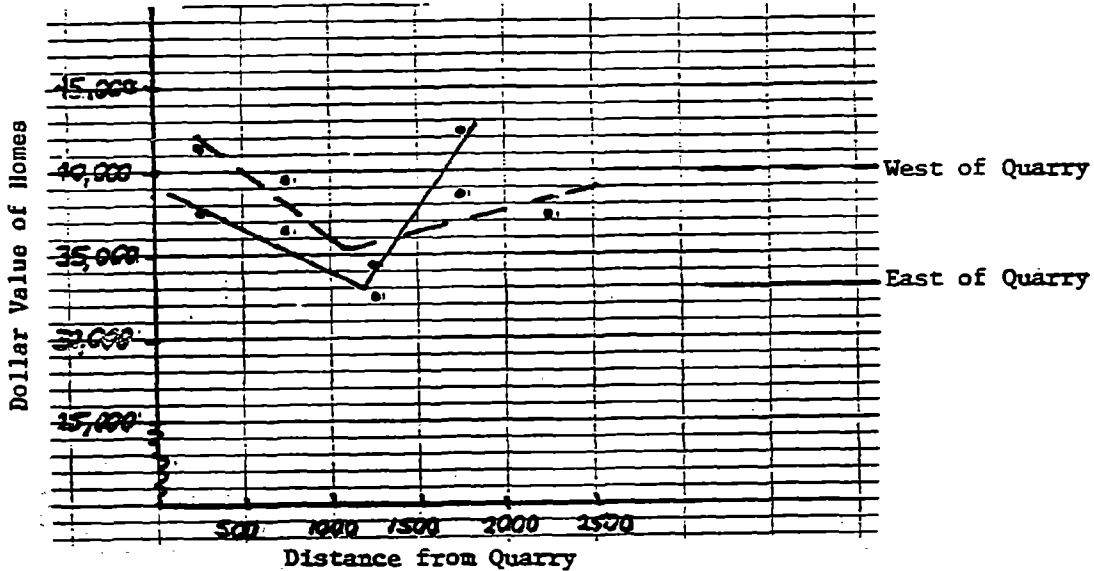
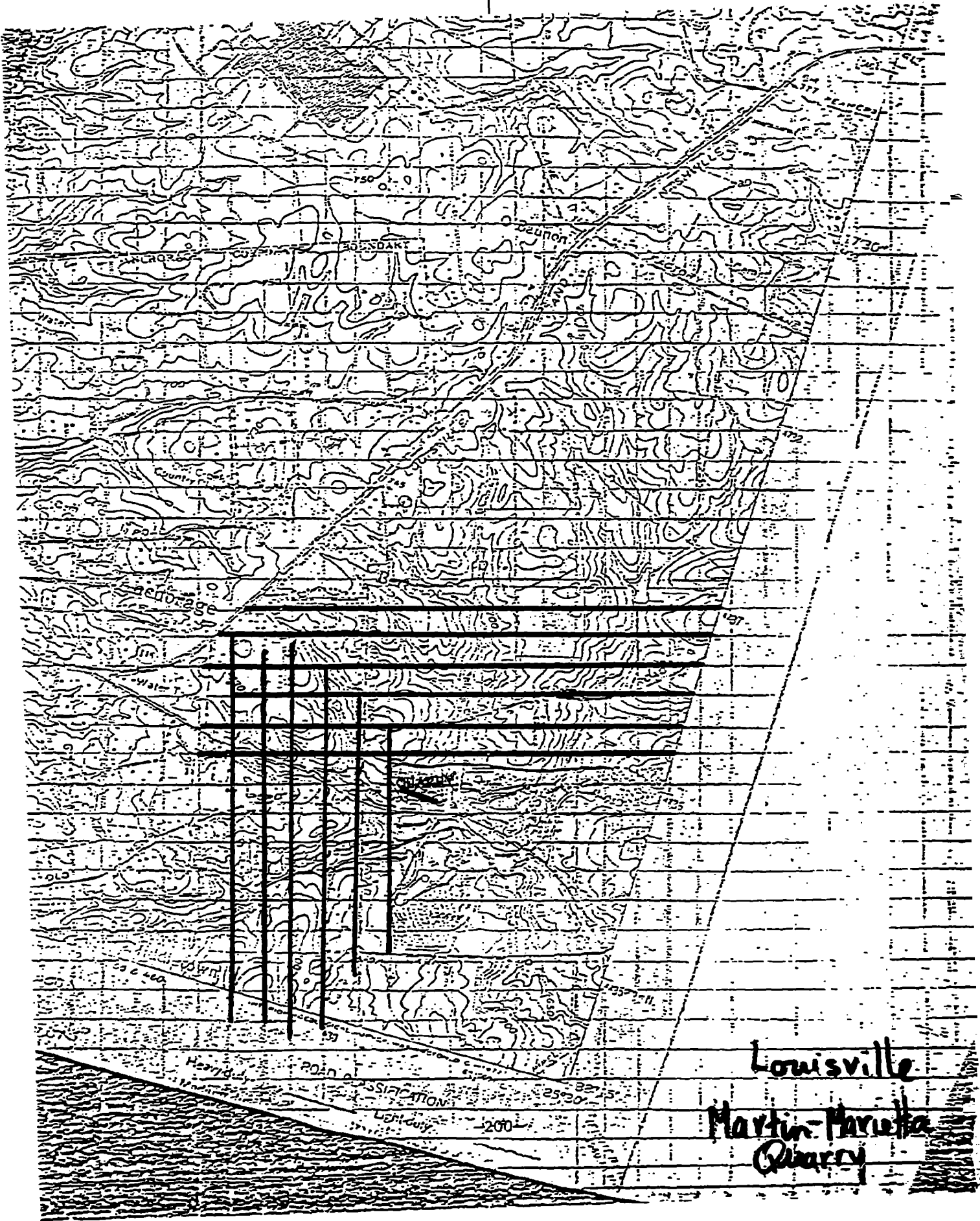


TABLE OF AVERAGE HOUSING VALUES

MATERIALS SERVICE QUARRY: COOK COUNTY, LYONS, ILLINOIS

Direction from quarry	Housing type	Distance from quarry (in feet)					
		0-500	500-1000	1000-1500'	1500-2000	2000-2500	2500-3000
North	(d)	-	-	61,981	61,895	-	-
	(e)	-	-	91,322	118,015	-	-
East	(a)	28,973	28,469	26,573	-	-	-
	(b)	31,552	33,173	32,573	-	-	-
	(c)	35,109	35,587	-	37,428	-	-
	(d)	38,689	40,395	42,831	40,216	-	-
	(e)	51,679	45,715	47,087	51,921	-	-
West	(a)	26,959	31,218	28,231	26,998	28,189	-
	(b)	33,231	32,776	32,678	32,981	32,808	-
	(c)	-	35,787	35,422	36,700	36,363	-
	(d)	40,293	40,132	41,382	40,532	40,216	-
	(e)	49,780	56,334	46,093	50,618	45,512	-
<u>ALL HOME AVERAGE</u>							
North		-	-	79,586	96,970	-	-
East		37,348	36,346	32,334	42,764	-	-
West		41,512	39,100	34,587	38,793	37,064	-



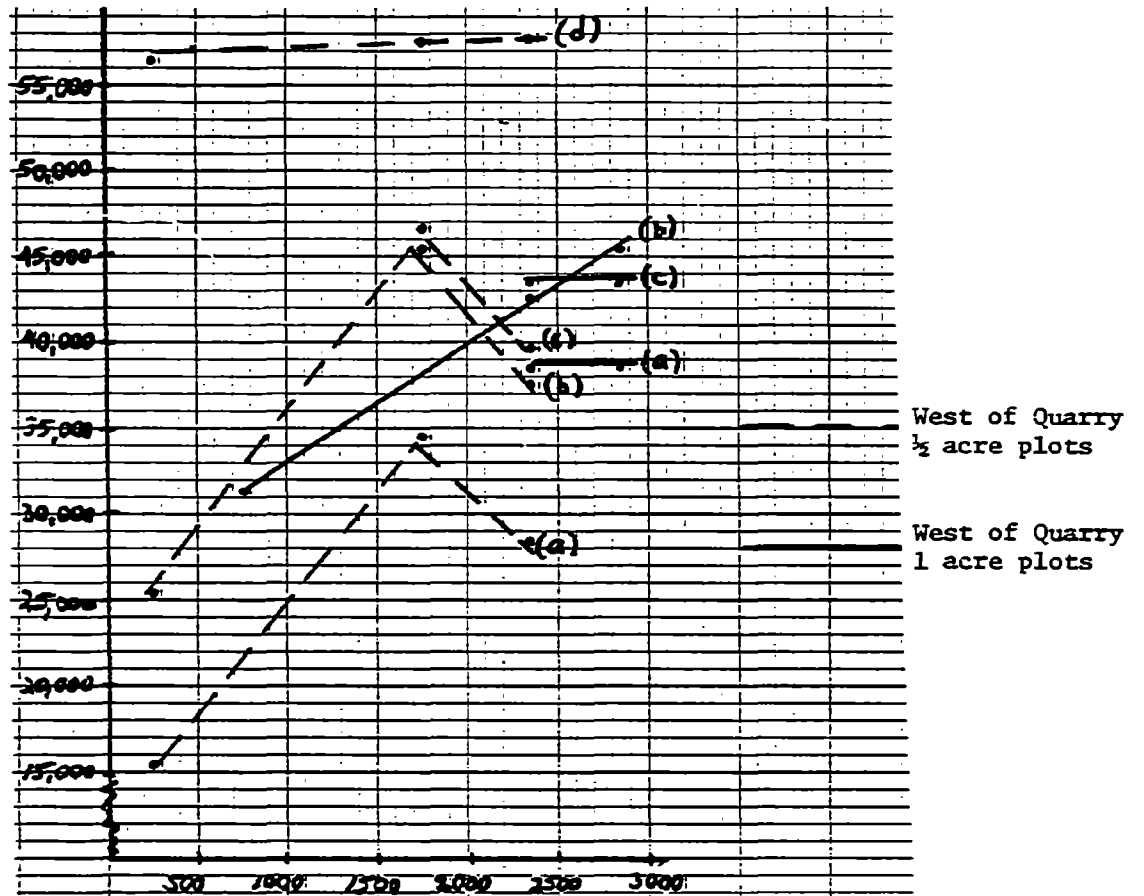
Louisville

Martin-Marietta
Quarry

Martin Marrietta Quarry

GRAPH 8

Average Housing Values by Category Measured Distance from Quarry



Martin Marietta Quarry

GRAPH 9

Average of All Housing Values by Distance from Quarry

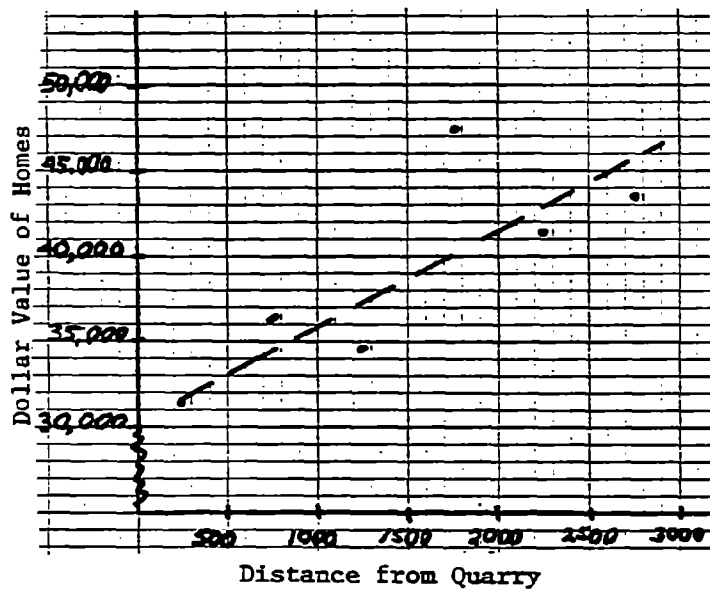


TABLE OF AVERAGE HOUSING VALUES

MARTIN-MARRIETTA QUARRY: JEFFERSON COUNTY, LOUISVILLE, KENTUCKY

Direction from quarry	Housing type	Distance from quarry (in feet)					
		0-500	500-1000	1000-1500	1500-2000	2000-2500	2500-3000
North	$\frac{1}{2}$ acre (a)	-	14,940	-	-	-	-
	1acre (a)	-	19,550	-	-	-	-
	2acre (a)	30,165	19,600	-	-	-	-
	$5\frac{1}{2}$ acre (a)	20,690	20,690	-	-	-	-
Northwest	$\frac{1}{2}$ acre (a)	-	17,820	25,500	-	-	-
	1acre (a)	-	31,830	-	-	-	-
	4acre (c)	-	82,000	-	-	-	-
West	$\frac{1}{2}$ acre (a)	15,500	-	-	34,865	28,620	-
	(b)	25,540	-	-	45,914	37,817	-
	(c)	-	-	-	46,870	39,736	-
	(d)	56,990	-	-	57,173	57,740	-
	1acre (a)	-	-	-	-	38,250	38,620
	(b)	-	31,790	-	-	42,250	45,227
	(c)	-	-	-	-	43,143	43,895
	(d)	-	-	-	-	65,390	-
	2acre (a)	-	27,780	23,700	-	-	-
	(b)	-	-	42,745	-	-	-
	(c)	51,080	-	-	-	-	-

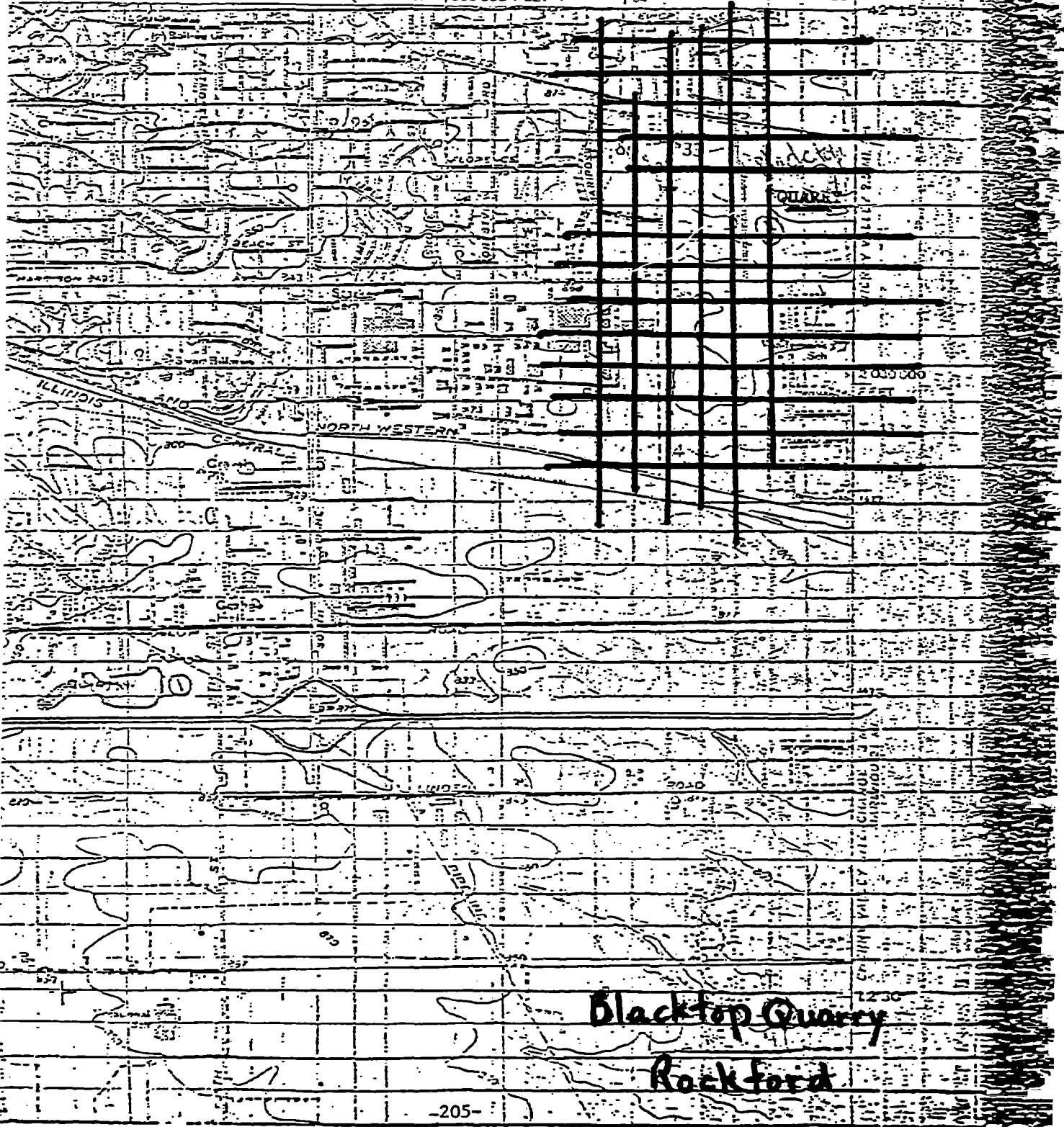
(cont.)

(Martin-Marrietta Quarry, Jefferson County, cont.)

Direction from quarry	Housing type	Distance from quarry (in feet)					
		0-500	500-1000	1000-1500	1500-2000	2000-2500	2500-3000
West	5 ¹ acre (a)	-	-	31,560	-	-	-
	(b)	-	49,450	-	-	-	-
<u>ALL HOME AVERAGE</u>							
North		27,006	16,152	-	-	-	-
Northwest		-	37,385	25,565	-	-	-
West		31,576	36,340	34,542	47,021	41,397	43,824

ILLINOIS
7.5 MINUTE SERIES (TOPOGRAPHIC)

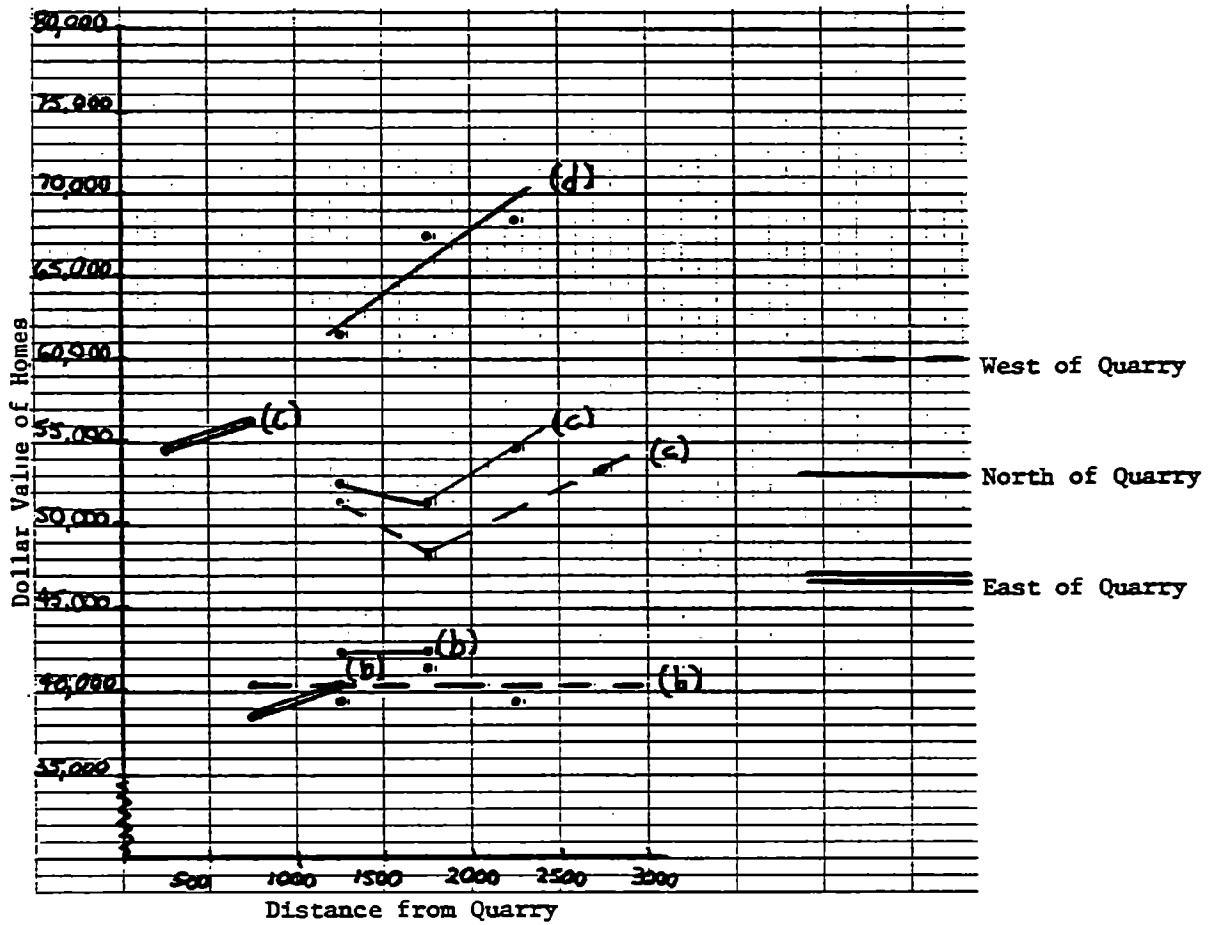
2° 30' ROCKFORD (COURTHOUSE) 3.9 MI. 1310000 FEET 89° 00'



Rockford-Blacktop Quarry

GRAPH 10

Average Housing Values by Category Measured Distance from Quarry



GRAPH 11

Average of All Housing by Distance from Quarry

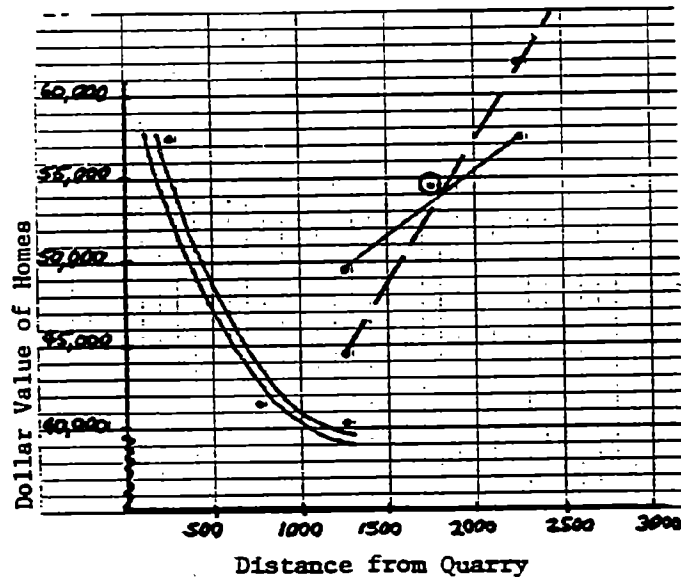


TABLE OF AVERAGE HOUSING VALUES

WINNEBAGO COUNTY, ROCKFORD, ILLINOIS

BLACKTOP QUARRY

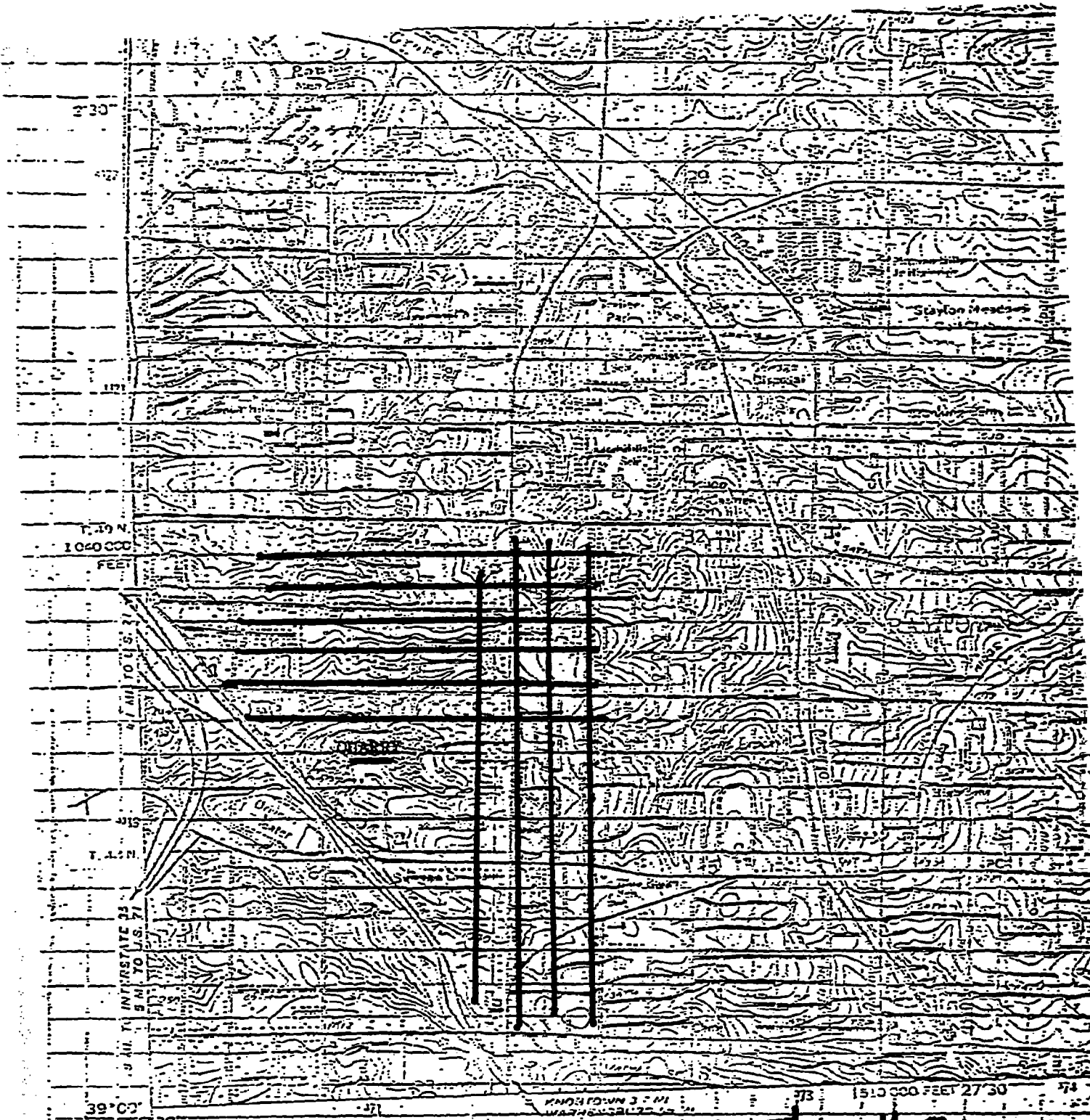
Direction from quarry	Housing type	Distance from quarry (in feet)					
		0-500	500-1000	1000-1500	1500-2000	2000-2500	2500-3000
North	(b)	-	-	42,888	42,166	-	-
	(c)	-	-	52,325	51,311	54,828	-
	(d)	-	-	61,924	67,414	68,848	-
	(e)	-	-	-	-	80,636	-
East	(b)	-	38,969	40,902	-	-	-
	(c)	54,833	56,272	-	-	-	-
	(d)	70,606	-	-	-	-	-
West	(b)	-	-	40,080	39,224	41,020	39,242
	(c)	-	-	51,992	48,262	-	53,909
	(d)	-	-	-	-	-	62,656

ALL HOME AVERAGE

North	-	-	49,989	54,710	62,194	-
East	57,987	41,853	40,902	-	-	-
West	-	-	44,845	42,613	41,043	50,666

CHERRY VALLEY QUARRY

East	(a)	-	32,404	32,287	32,647	-	-
	(b)	-	37,282	37,666	38,151	-	-
	(c)	-	-	-	45,606	-	-
West	(b)	-	-	43,696	-	-	-
	(c)	-	-	54,157	-	-	-
	(d)	64,979	66,919	-	-	-	-
	(e)	75,272	70,106	82,292	-	-	-
	<u>ALL HOME AVERAGE</u>						
East	-	34,843	34,080	35,028	-	-	
West	67,553	67,716	59,006	-	-	-	



1:50,000
 1:50,000
 1:50,000

Mapped, edited, and published by the Geological Survey
 in cooperation with State of Missouri
 Geological Survey and Water Resources
 Control by USGS, USCGS, and USCE

63rd & 50th Quamy
 K.C.

Planimetry by photogrammetric methods from aerial photographs
 taken 1955. Topography by aneroid observations
 Revised 1954

-208-

Polyconic projection. 1927 North American datum
 10,000-foot grid system, west zone
 1,000-meter Universal Transverse Mercator grid ticks,
 zone 15, shown in blue

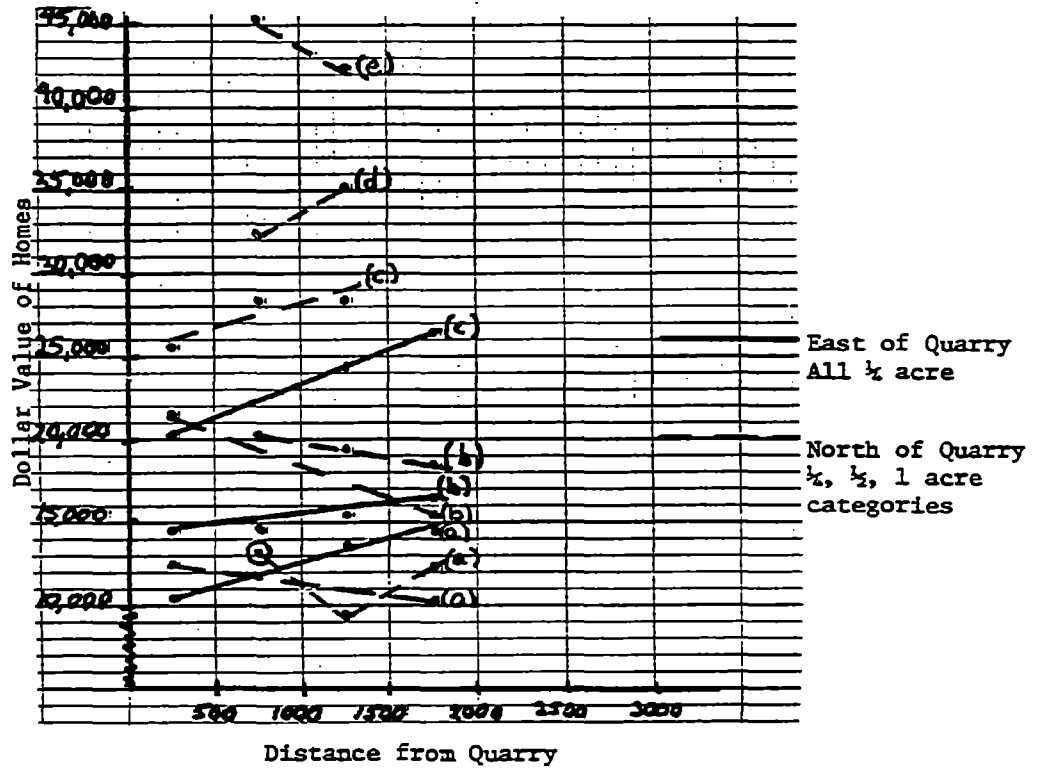


DECISION AS TO THE
 LOCATION OF THE CENTER OF THE

Kansas City 63rd and Rt. 50 Quarry

GRAPH 12

Average Housing Values by Category Measured Distance from Quarry



GRAPH 13

Average of all Homes by Distance from Quarry

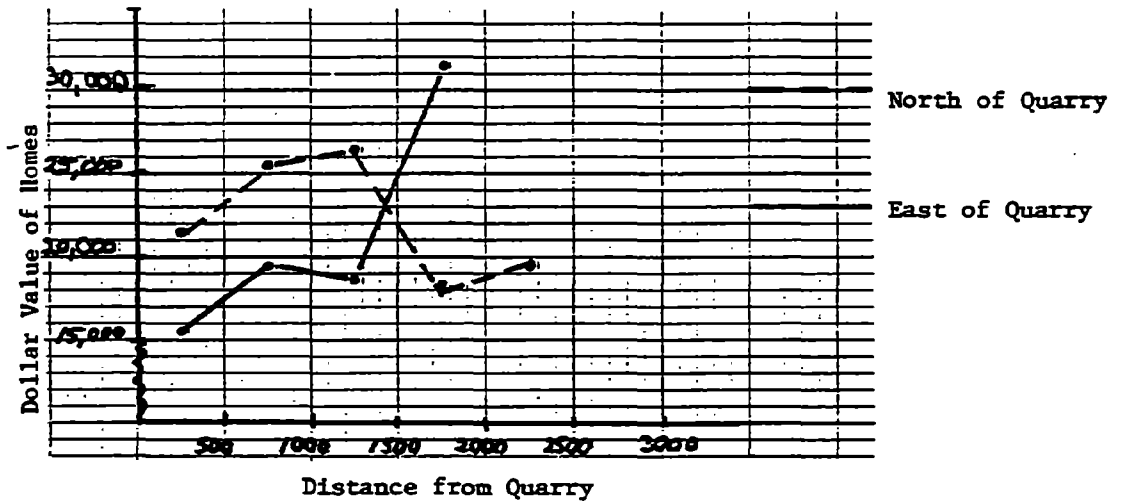


TABLE OF AVERAGE HOUSING VALUES

JACKSON COUNTY, KANSAS CITY, MISSOURI

63rd & ROUTE 50 QUARRY

Direction from quarry	Housing type	Distance from quarry (in feet)					
		0-500	500-1000	1000-1500	1500-2000	2000-2500	2500-3000
North	$\frac{1}{4}$ acre						
	(a)	-	-	-	13,772	13,775	-
	(b)	-	-	-	15,204	-	-
	(c)	-	28,325	28,635	-	-	-
	(d)	-	32,852	35,613	-	-	-
	(e)	-	45,078	42,272	-	-	-
	$\frac{1}{2}$ acre						
	(a)	-	12,495	-	10,726	-	-
	(b)	21,795	20,030	19,878	18,317	-	-
	(c)	25,454	-	-	18,000	-	-
	1acre						
	(a)	-	13,477	9545	12,454	-	-
	(b)	16,112	-	-	20,090	-	-
	(c)	26,409	-	-	27,000	-	-
	East	$\frac{1}{4}$ acre					
(a)		10,499	13,386	13,668	14,707	-	-
(b)		14,863	14,958	15,624	15,663	-	-
(c)		20,181	-	24,153	26,264	-	-
(d)	-	-	32,757	34,136	-	-	
<u>ALL HOME AVERAGE</u>							
North		21,218	30,132	31,060	14,044	13,775	-
East		15,192	13,467	21,676	20,020	-	-

(Jackson County quarries cont.)

(Jackson County quarries cont.)

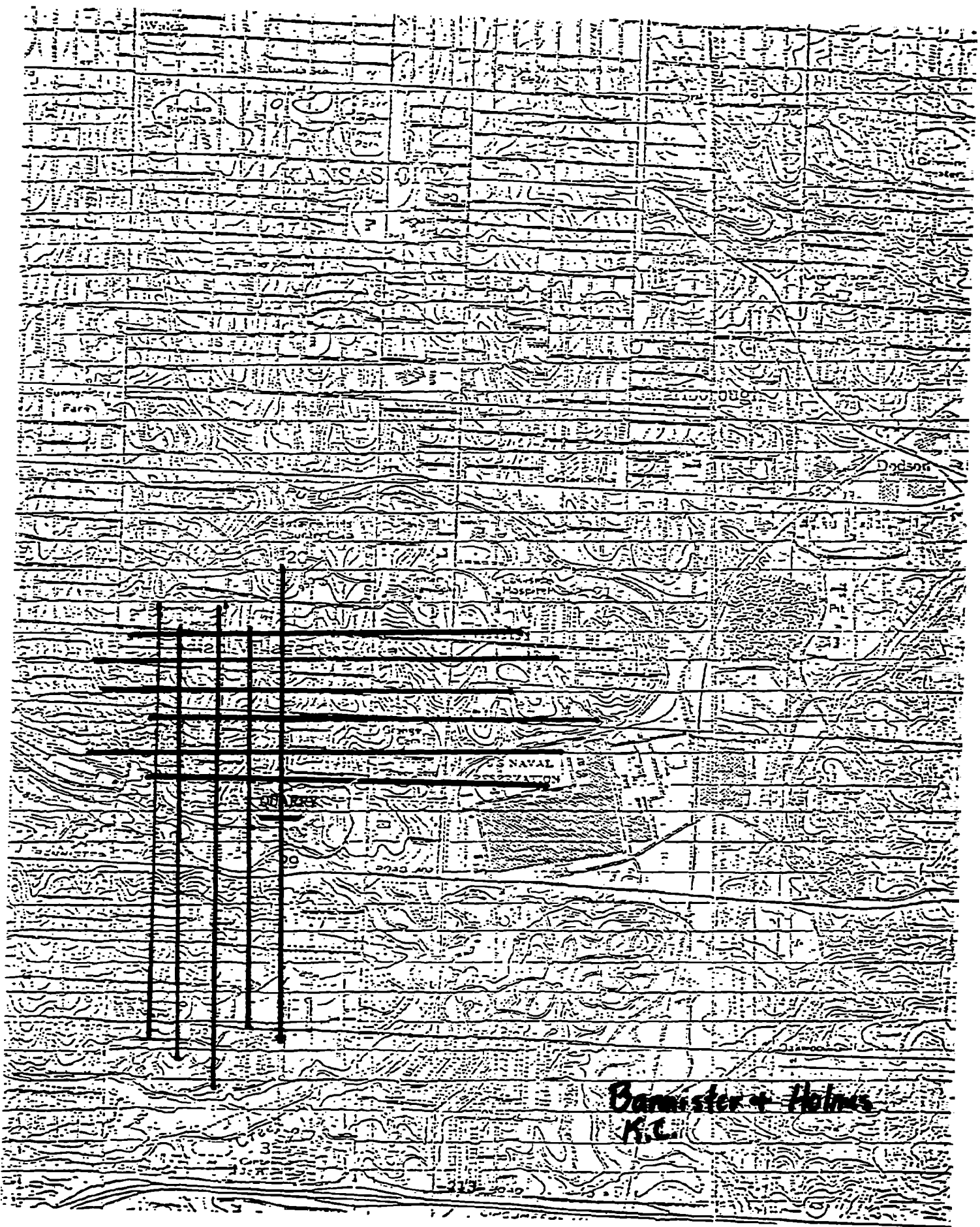
HOLMES & BANNISTER QUARRY

Direction from quarry	Housing type	Distance from quarry (in feet)						
		0-500	500-1000	1000-1500	1500-2000	2000-2500	2500-3000	
North	$\frac{1}{4}$ acre (a)	11,018	-	-	-	-	-	
	(b)	16,124	19,598	20,077	23,080	-	-	
	(c)	-	25,145	27,123	27,136	-	-	
	(d)	-	-	30,726	32,575	-	-	
	$\frac{1}{2}$ acre (a)	-	-	-	-	-	-	
	(b)	22,067	20,329	-	-	-	-	
	(c)	29,409	-	-	-	-	-	
	South	$\frac{1}{2}$ acre (b)	-	19,317	-	-	-	-
		(c)	-	24,656	-	-	-	-
		(d)	-	27,954	-	-	-	-
		1acre (b)	-	-	18,848	-	-	-
		(c)	-	26,571	-	-	-	-
(d)		-	30,499	35,909	-	-	-	
Southwest	$\frac{1}{4}$ acre (b)	-	17,352	-	-	-	-	
	(c)	-	21,529	-	-	-	-	
	West	$\frac{1}{4}$ acre (a)	9792	13,294	11,601	-	-	
(b)	16,135	18,335	15,484	-	-	-		
(c)	-	-	27,726	29,777	-	-		
(d)	-	-	36,613	33,420	-	-		
(e)	-	-	-	39,090	-	-		

(cont.)

(Holmes and Bannister Quarry Averages cont.)

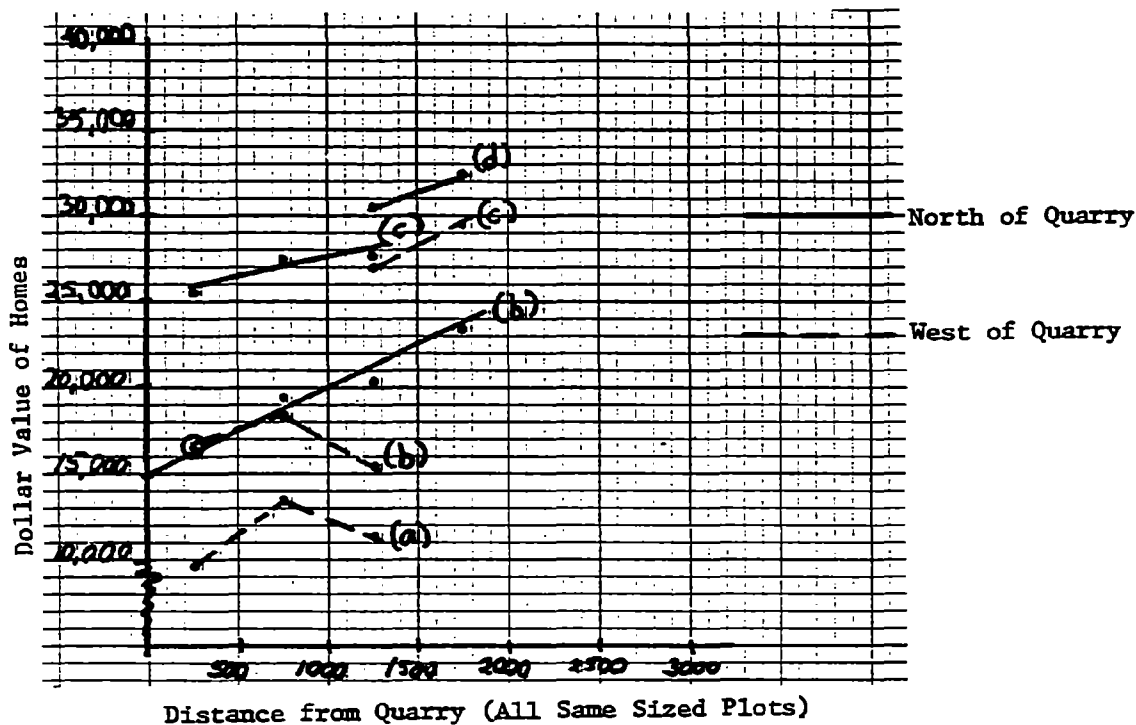
<u>ALL HOME AVERAGE</u>						
<u>Direction from quarry</u>	<u>Distance from quarry (in feet)</u>					
	<u>0-500</u>	<u>500-1000</u>	<u>1000-1500</u>	<u>1500-2000</u>	<u>2000-2500</u>	<u>2500-3000</u>
North	19,302	22,818	27,191	28,194	-	-
South	-	25,723	20,554	-	-	-
Southwest	-	19,275	-	-	-	-
West	15,257	17,035	18,701	31,913	-	-



Kansas City Holmes and Bannister Quarry

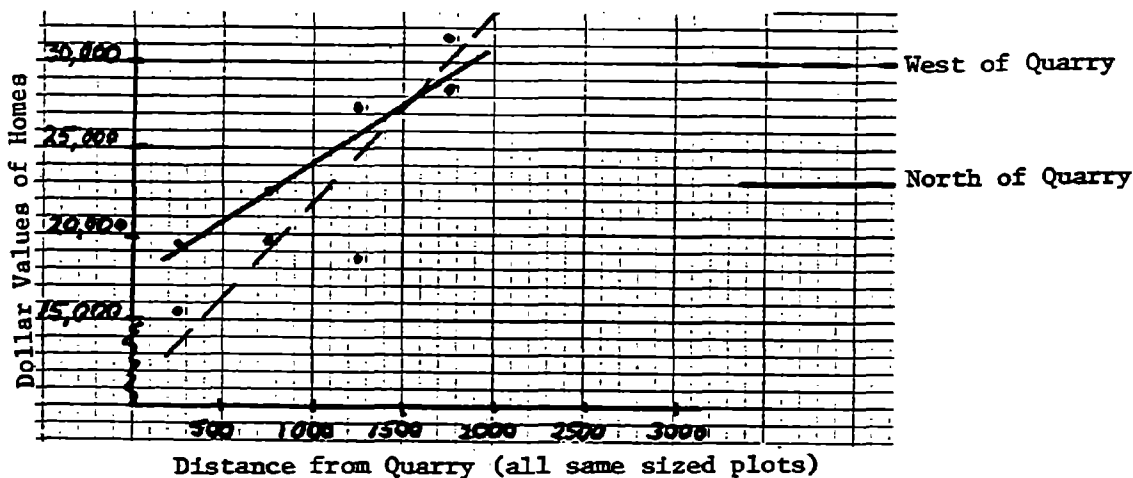
GRAPH 14

Average Housing Values by Category Measured Distance from Quarry



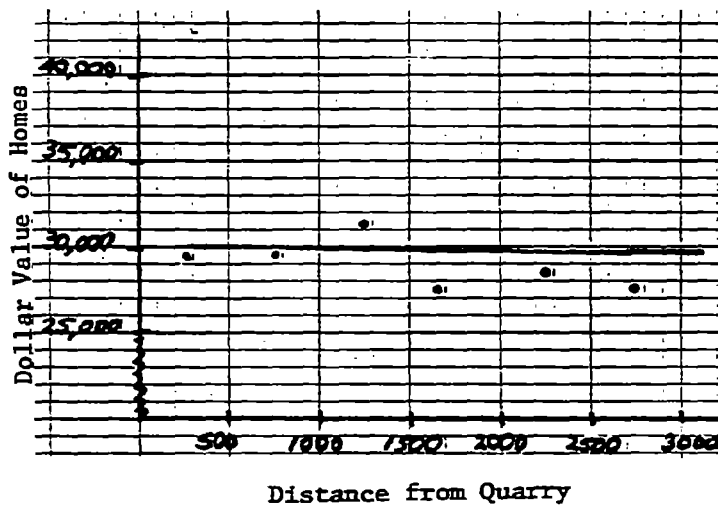
GRAPH 15

Average of All Homes by Distance from Quarry



GRAPH 16

Average of All Sites of All Homes by Distance from Quarry



PART FIVE

BLAST INDUCED CRACKING:
DIFFICULTIES OF DEFINITION AND INSPECTION

I. INTRODUCTION

Many investigators around the world have studied the effects of blasting from surface mining, quarrying and construction on low-rise residential structures. The major objectives of most of these studies were (a) to establish reliable damage criteria, that is, correlations between blasting effects (such as ground vibration) and resulting cracking in structures, and (b) to establish correlations between various parameters which affect the magnitude of ground vibrations. However, there are significant problems associated with consistency or comparability of damage classification systems.

A review of available literature indicates that (a) blast-induced damage has not been defined adequately, (b) little attention has been given to effects of wall covering materials on cracking criteria, (c) cracking criteria are of necessity probabilistic because of the number of factors of crack initiation, and (d) human response to noise and vibration affects a realistic damage assessment from post blast inspection.

Current practice or literature does not provide a basis for developing a comprehensive, detailed classification scheme which would have any likelihood of becoming widely accepted. It is nonetheless important that more accurate descriptors be utilized. It is therefore recommended:

- 1) That the term cracking be used instead of the term "damage".
"Cracking" is a non-perjorative, emotion-free term which is properly descriptive, regardless of degree of severity. The term "damage" is an emotion-laden word that implies a high degree of severity, regardless of actual severity.
- 2) That evaluation of the severity of cracking in specific cases be made with respect to aesthetic (cosmetic), engineering (load loss) and economic (cost of repair) dimensions. The cost of repair evaluation would apply to both cosmetic and load loss cracking.
- 3) That a judicial brief be prepared under the auspices of the American Bar Association to define (for legal purposes) the technical issues in blast induced cracking and to separate the technical aspects of cracking from annoyance.

The information and discussion presented in this section will attempt to provide some insight to the above conclusions. Available literature will be employed and annoyance and construction blasts will not be considered.

II. LEGAL DEFINITION

In general, engineering, administrative and legal definitions could be used to determine the occurrence of damage and/or the severity of damage inflicted upon residential structures from nearby blasting operations.

Although a significant number of claims and lawsuits are brought every year against the operators and/or the owners of surface mines and quarries, a comprehensive legal definition of blast damage has not yet been formulated. This legal void could be due to the fact that the term damage itself must legally remain undefined and thus is a very broad term and/or the observation of damage occurrence and the quantification of damage severity are highly subjective in many cases. Since there is no legal definition of damage, discussion is limited to administrative and engineering definitions.

III. ADMINISTRATIVE DEFINITION

Administrative definitions are also very limited. In an attempt to correlate ground vibration to structural damage, Scholl (1976)*obtained information from the damage complaint and payment records of the AEC (Atomic Energy Commission). To establish the validity of damage, each complaint was first investigated by an insurance adjuster, and, if there was any question as to whether the damage had been caused by an underground nuclear explosion test, an engineering investigation was conducted. The following two definitions were advanced:

- a) Complaint: Any complaint made concerning property damage whether or not formalized on a claim; and
- b) Credible Damage: Any of the above-described complaints acknowledged as credible by investigators.

Investigators responded to post-blast complaints. Thus, the credible cases are subject to all of the difficulties associated with post-blast complaint inspections, which are discussed in a later section. Furthermore, the social interactions of the agency with the complainants must be taken into account.

The International Standards Organization (Tunnels and Tunneling, 1977) has considered proposing the following classification:

- a) Category 1: Threshold damage consisting of visible cracks in non-structural members such as partitions, facings, and plaster walls and, as a guideline, visible cracks may be taken as those with a width of 0.02 mm.;
- b) Category 2: Minor damage consisting of visible cracks in structural members such as masonry walls, beams, columns, slabs and no serious reduction in load-carrying capacity;
- c) Category 3: Major damage consisting of large permanent cracks in non-structural members, settlement and displacement of foundations which may result in the reduction of load-carrying capacity.

*References for this chapter will be found in the complete final bibliography.

Cracking thresholds are defined on the basis of use; and range from 1.6 millimeters per second for residences (0.06in/sec) to 18 millimeters per second (.71 in/sec) for offices.

IV. ENGINEERING DEFINITIONS

A careful review of existing literature indicates that numerous definitions of blast induced damage of residential structures have been advanced and/or adopted by engineers and scientists conducting experimental investigations, research, and field surveys. A representative sample of these definitions is provided next:

1. For purposes of relating vibration energy to damage, Edwards and Northwood (1960) separated damage in three categories:
 - a) Threshold of damage: opening of old cracks and formation of new plaster cracks, dislodging of loose objects (e.g.: loose bricks off chimneys);
 - b) Minor damage: superficial, not affecting the strength of the structure (e.g.: broken windows, loosened or fallen plaster) hairline cracks in masonry;
 - c) Major damage: resulting in serious weakening of the structure (e.g.: large cracks or shifting of foundations or bearing walls, major settlement, walls out of plumb).
2. Three degrees of damage were also distinguished by Dvorak (1962):
 - a) First degree (threshold of damage): Loosening of the painting, small fissures in the plaster or at the joints between two different construction elements;
 - b) Second degree (minor damage): Cracks appear in the masonry, especially around openings or where partition walls are joined to the main ones. The width of crack is from hairline to 2 to 3 mm. Loosening and falling of plaster.
 - c) Third degree (major damage): Cracks several mm. wide through main walls, rupture of opening vaults, substantial weakening of the structural strength.
3. A damage evaluation survey by Barnes (1977) arbitrarily defined abnormal failure (or blast induced damage) to be indicated by (a) more than two cracks larger than a hairline, (b) more than two cracks longer than three feet in the superstructure and five feet in the basement, and (c) more than two cracks.

It becomes apparent that investigators attempt to distinguish the "no-damage" versus "damage" conditions by loosely, and usually non-quantitatively defining a "threshold" of damage. Attempts to quantify such a threshold of damage have resulted in high variability. According to

the studies summarized in Table 1, the threshold of damage obtained or reported by different investigators vary by at least one order of magnitude (lower values of 0.1 to 0.4 in/sec, higher values of 4 to 8 in/sec).

With respect to damage severity, minor and major damage categories are identified; minor damage is usually "cosmetic" and major damage is associated with "loss of structural integrity". The inability of a structure to carry the maximum design loads or to perform according to design specifications is considered to be loss of a structural integrity. Thus, any other type of damage can be considered as cosmetic. Actually, the reason for many complaints and grievances is only cosmetic cracking of walls.

It is concluded that the current attempts at classification of damage suffer not only from lack of consistency but also from the use of vague, misleading, and commotative terminology. Therefore, it would be useful to have more precise, commotation-free descriptors; specifically:

- 1) the use of the term "cracking" instead of the term "damage";* and
- 2) evaluation of the severity of cracking in terms of three separate dimensions:
 - a) aesthetic (cosmetic cracking)
 - b) engineering (load loss cracking)
 - c) economic (cost of repair, applied to both cosmetic and load loss cracking).

Further, a legal definition of cracking needs to be established, but this would best be done by the legal profession.

V. ORIGINS OF CRACKING (DAMAGE)

Damage to residential homes and associated structures has been attributed to three different effects of nearby blasting operations: (a) ground vibrations and stress waves, (b) air blast waves, and (c) debris or flyrock. The types of damage caused by each of these effects is summarized in Table 2 and a brief discussion of their significance and probability of occurrence is presented next.

1. Airblast

When explosives are detonated in the air, on the ground, or in the ground but near the ground surface, nearby structures are subjected to

* since the term damage is used in the studies reviewed, the term will be used in the discussion which follows both to avoid improper attribution of terminology to the sources and to illustrate the inadequacy of the term.

an air blast. Window glass failure usually occurs (at lower overpressures) before any other type of structural failure (Perkins, Lorain, and Townsend, 1960; Perkins and Jackson, 1964; Nicholls, Johnson and Duvall, 1971). Review of available information (Nicholls, Johnson and Duvall, 1971; Siskind, 1974; Ladegaard-Pedersen and Dally, 1975; Foster, 1975; and Redpath, 1976) indicates that conventional blasting operations using well stemmed holes and complying with present regulations for safe blasting result in airblast overpressures which are considerably below (an order of magnitude or more) those required to produce damage to window glass. The probability of damage increases if the glass panels are at a strain state very close to their critical strains or if inappropriate construction practices were employed. Air blast induced vibration may modify structural response to ground vibration (Fulthorpe, 1979); however, no definitive study has been conducted.

2. Flyrock

There is an apparent lack of information with respect to the characteristics of the debris or flyrock which are generated from borehole blasting operations. It is, however, logical to assume that any flyrock reaching a structure is a potential source of damage to the exterior of the superstructure. On the basis of a relatively extensive study, Ladegaard-Pedersen and Dally (1975) concluded that (a) the maximum throw from the bench face can be controlled by adjusting the specific charge, and (b) cratering effects can be minimized or eliminated by employing appropriate stemming lengths and cover.

3. Ground Vibrations

The major source of damage to residential homes and associated structures are the stress waves generated during blasting which can (a) induce vibration to structures, (b) strain the ground around structures, and (c) change the volume of soils due to instantaneous densification. In general, any of these phenomena can result in cracking of structural components. With respect to residential houses or similar structures (churches, schools, etc.) cracks may develop in the superstructure, in basement walls, and in the foundations. This damage can be either in the form of cosmetic cracks or may result in loss of structural integrity if the load carrying capacity of structural elements has been reduced. With respect to other buried structures, such as septic tanks and pipelines, cracking should be considered as loss of structural integrity since fluid will inevitably leak. Densification of loose sand and silt layers can result in changes of the existing groundwater flow pattern and may adversely affect the productivity of wells; however, such densification has been observed only very close to blasts. Vibratory densification of other soils is unlikely.

In summarizing the above discussion, it can be stated that: (a) the probability of occurrence of airblast-induced damage is significantly smaller than that from flyrock or ground stress waves, (b) in cases where flyrock cannot be effectively controlled, any damage resulting from

flyrock could probably be identified as such. Furthermore, available information is extremely limited with respect to damage induced to structures other than residential houses. Therefore, damage from air-blast and flyrock will not be considered further, and the rest of this discussion will concentrate on blast induced damage in residential structures.

VI. CRACKING IN RESIDENTIAL STRUCTURES

Wall covering, stress concentrations, fatigue and quality of construction control the critical strains, ϵ_c , which must be exceeded for cracks to develop in residential structures (Dowding, Beck, Atmatzidis 1980). The mechanisms by which cracking may occur in residential structures are outlined in Table 3. In general, cracking is the result of excessive straining which is statically and/or dynamically induced.

1. Non-Dynamic Mechanisms

Differential foundation settlement, excessive structural loads, and deterioration or drying of construction materials can all induce significant strains to a residential structure. For example, differential settlement observed in residential structures is frequently attributed to consolidation of the foundation soil caused by the transpiration processes of nearby trees (Perpich, Lukas, and Baker, 1965; Bozozuk, 1967; Burns and Penner, 1975). Other major mechanisms of differential movement of the foundations include: (a) bearing capacity failure, (b) volume change of foundation soil due to shrinkage, swelling, dewatering or compression, (c) frost action, and (d) erosion. Excessive structural loads or roof trusses, floors, and lintels can be the result of snow accumulation, strong wind, water ponding, and excessive dead weight. Some possible causes of construction material deterioration which may result in cracking are wood shrinkage and decay, mortar drying and chemical corrosion, insufficient curing of concrete blocks, corrosion of steel members, water leakage, and vapor infiltration.

Thermal expansion and contraction can cause new cracks to develop or existing cracks to propagate through fatigue. Wall (1966) and Nelson (1967) observed and analyzed the response of cracks in concrete block walls to: a) daily temperature variations in a desert environment; b) straining from ground vibrations due to nuclear detonations. They concluded that movements of cracks were primarily a function of the thermal cycle. Wiss and Nicholls (1974) monitored the movement of cracks in gypsum drywall interior wall covering during a period of deliberate blasting to induce cracking. Their measurements during a non-blasting period as well as those by Wall (1966) and Nelson (1967) indicate that daily thermal cycles induced crack movement of up to 0.005 in. Movements this large can induce significant strains in walls which are not stress-relieved by crack movement. These daily, temperature-induced strain cycles could lead to loss of strength through material fatigue.

Since static loading mechanisms are frequently irreversible, it is safe to assume that, at any given point in time, the walls of residential structures may be under some state of strain although cracking may not be apparent. Anyone familiar with old homes has seen the cracks which are manifestations of such distortion induced strains.

2. Dynamic Straining

Residential structures selectively amplify and filter incoming ground motions and the resultant structural motions induce dynamic strains in walls. Three major factors control the induced strains: (a) the vibration time history, (b) the type of home, and (c) the critical structure component. For example, multiple delay blasts will cause greater structural motions than a single delay blast (Dowding, 1971); single-story houses amplify higher frequency motions more than multiple-story houses (Mediaris, 1975); and concrete cantilever balconies respond differently than do walls of wood frame houses.

The foregoing discussion may be summarized by stating that cracks in residential structures may develop and/or propagate for reasons other than blast induced dynamic strains.

VII. CRACKING (DAMAGE) CRITERIA

Through the years, various criteria and indices have been suggested for estimating blast-induced damage to structures. A comprehensive review is given in Table 1. Initially, particle acceleration was considered to provide an adequate basis for the formulation of such criteria (Thoenen and Windes, 1943). The concept of energy ratio, which is a function of particle acceleration and ground vibration frequency, was later developed (Crandell, 1949) and recommended for use. Subsequently, investigators concluded that ground particle velocity in the vicinity of a structure correlated best with observed damage and recommended "safe" limits for the value of this velocity (Edwards and Northwood, 1960; Dvorak, 1962; Duvall and Fogelson, 1962; Langefors and Kihlstrom, 1968; Northwood, Crawford and Edwards, 1963; Nicholls, Johnson, and Duvall, 1971; Wiss and Nicholls, 1974; and others). Although peak particle velocity is considered a good index of damage or damage potential, other methodologies have been proposed for predicting damage potential and are based on the use of response spectra (Dowding, 1971) or on the determination of pseudo spectral relative velocities (Medearis, 1976).

Since peak ground particle velocity constitutes the accepted (by law and regulation) criterion for designating safe blasting limits, it should be further discussed. A peak particle velocity of 1 in/sec (OSM) measured on the ground is considered at this time as a safe limit to prevent structural damage (cracking). According to the damage threshold defined by numerous investigators (Table 1) these values can be considered as rather conservative.*

* However, there are investigations involving original data (Dvorak, 1962; Wall, 1966) where a lower damage threshold was observed. These studies either cannot be verified or involve nuclear blast induced ground motions.

Of the twenty-one studies summarized in Table 1, the last seven are based on information which was obtained from previous studies; of the first thirteen studies, two were conducted on model structures (Crawford and Ward, 1965; Wendler et al., 1975), four monitored only one house, and three monitored four to six houses. The number of observations on which the development of the velocity criterion is based is rather limited. Furthermore, the following observations can be made:

- a) The structures tested ranged from wood frame houses to reinforced concrete frame structures.
- b) The age of the structures tested was highly variable; some houses were over 50 years old and others were abandoned for some time.
- c) The stress history of the houses tested was completely unknown and no evaluations could be advanced with respect to pre-existing strains.
- d) Damage was observed at differing locations with varying inspection procedures.
- e) The ratio of the blast excitation frequency and building response frequency was rarely considered.

The available criteria provide at best only an index of blast-induced strains (ϵ_d) because wall material, existing strains, ϵ_s , and fatigue strength reduction are not explicitly considered. Pre-existing strains (prestrains) and cyclic thermal straining (which could lead to fatigue) are well documented for structures. Furthermore, the peak particle velocity criterion is based solely on ground motion and does not take into account the dynamic characteristics of the structure itself.

It appears that, for day to day applications, use of a simple criterion for evaluating the damage potential of ground vibration can be recommended if the frequency of excitation, building height (or natural frequency) and wall cover material (type and existing strain state) are included. The peak ground particle velocity can serve as an index by which such a criterion can be based. However, these criteria are probabilistic in nature and a blanket recommendation and/or acceptance of a single velocity value as the "safe blasting limit" should be viewed as a very simplistic and overconservative approach.

VIII. OBSERVATIONS OF CRACKING

Damage claims (in a legal sense), which may or may not be legitimate, result from observations of cracks in the walls of residential structures. Such observations are made by any of the following three methods: (a) the owner or resident of a home observes the cracks and attributes them to nearby blasting, (b) professionals conduct post-blast surveys and decide on the origins of cracks, and (c) professionals conduct pre-blast surveys and post-blast surveys and may monitor parts of the structure during blasting. The last method has been used primarily in research projects, and is the only way statistically induced cracks can be distinguished from blast induced cracks at the threshold level.

1. Human Response

Ground vibration and accompanying air blast noise that are completely safe for structures may be subjectively perceived by people as annoying and uncomfortable. For example, a particle velocity of 0.2 in./sec. may be quite unpleasant or annoying to some persons (Nicholls, Johnson, and Duvall, 1971; Ladegaard-Pedersen and Dally, 1975). However, this value is one order of magnitude lower than the 2 in./sec. criteria and the probability that it can cause cracking in homes is minimal if not nil.

A similar subjective response may be due to the noise associated with air blast overpressures. For example, the sound level at an overpressure of 0.01 psi is comparable to the maximum sound in a boiler shop or the sound level 4 feet from a large pneumatic riveter (Nicholls, Johnson, and Duvall, 1971). This overpressure is more than one order of magnitude lower than that which can cause glass damage.

Since most people cannot be expected to know or understand the technology of blasting and the causes of cracks in homes, it is not surprising that they may interpret some actually harmless ground vibrations and air blast overpressures as potentially dangerous to their property. Thus, having subjectively decided that damage has been inflicted upon their property, these people will devote time and effort in identifying cracks (old or new) in the walls of their homes and will, most probably, attribute all of them to the blasting operations.

2. Post-Blast Surveys

Homeowners find it difficult to prove that blasting is the cause of cracking that they observe and frequently invite or hire a professional or an "expert" to conduct a post-blast cracking assessment. Although the conclusions of such an assessment can be strongly disputed, they often result in property owners receiving restitution. Morgan et al. (1978) discuss the methods used by Dr. Charles Bartlett, a geology professor from Virginia, who conducts post-damage inspections. Through five years of experience, Dr. Bartlett has identified certain cracking patterns due to blasting, has formed a check list of possible damage from blasting, and inspects for the following: (a) cracking due to differential settlement of foundations, (b) cracking pattern in foundations, (c) cracking pattern in exterior walls, (d) cracking of inside wall coverings, and (e) effects on water wells. Although extreme care and caution may be taken in conducting such a post-blast survey and cracking assessment, it should be pointed out that this approach is based totally on after the fact observations and does not involve any experimentation, instrumentation, or theoretical analyses. Considering the multiplicity of causes of cracking in houses, many years of experience would be required to separate dynamic cracking from other types.

The shortcomings of cracking assessment based on post-blast surveys can be further illustrated by reviewing a study conducted by Barnes (1977). Out of approximately 1300 residences in a three mile radius area around a mine, 169 residences were surveyed by non-professionals (students,

concerned neighbors, parishioners). These observations were combined with statements signed by the residents, and blast induced cracking was identified. The scope and usefulness of such assessments are severely limited by the fact that no scientific investigation was conducted and only subjective opinions and arbitrary criteria were utilized. Almost any home over 50 years of age will be more cracked than the above defined threshold level.

3. Pre-Blast Surveys

The difficulty of assessing blast induced cracking on the basis of post blast surveys has long been realized and insurance companies (National Board of Fire Underwriters, 1956) instruct and educate their adjusters on the identification of the causes of apparent cracks. Furthermore, recent Office of Surface Mining regulations have called for pre-blast surveys of residences within a certain distance from blasting operations. A pre-blast survey should have three primary objectives: (a) education of the impacted residences using available information on the causes of cracking, the severity of cracks, and the sensitivity of humans to noise and vibration, (b) documentation of cracks by sketching, photography, and continuous monitoring, and (c) collection of structural and geotechnical information for use in the evaluation of the response of the structure to ground vibrations and possible settlement problems.

Pre-blast surveys may be more harmful than beneficial if conducted in a hurried (lowest bid price) manner. Unrecorded, but pre-existing cracks may be noticed by homeowners during blasting or by post-blast surveyors. Crack documentation should involve some form of photography recording as photographs or video tapes which are much less contestable and have a greater impact than sketches. Continuous monitoring of existing cracks or of areas that are most susceptible to cracking (corners, joints, areas near door and window openings) may not be necessary for day-to-day operations but can provide valuable input to research projects.

IX. CONCLUSIONS AND RECOMMENDATIONS

Based on the information and discussions presented herein, the following conclusions can be advanced:

1. Blasting operations in surface mines and quarries can cause cracking in nearby residential structures; damage from flyrock is self-evident; cracking from air-blast waves has a rather low probability of occurrence; ground vibrations are the major source of cracking.
2. Blast-induced damage is poorly defined; legal definitions are non-existent; administrative definitions are scarce; engineering definitions of structural damage (such as "threshold", "minor" and "major") have generally been derived empirically, are rather vague, and subjective, and although similar, are not uniform.

3. Numerous factors other than blast-induced dynamic strains, cause cracks to develop and/or propagate in the walls of residential structures; some cracks should be expected to exist in practically all low-rise residential structures and especially in older homes.
4. Cracking criteria or indices are probabilistic in nature; a uniform "safe blasting level" based primarily on monitoring of the response of older, and sometimes abused structures may be overly restrictive with respect to newer structures. Age, construction practice, material quality, and previous stress history control the critical strains in a structure. Furthermore, the excitation frequency of the ground motions affects the induced dynamic strains and must be accounted.
5. Pre-blast surveys are necessary for a realistic assessment of blast-induced damage, as observations by residents during blasting can be biased due to the effects of human response to vibrations and noise. Assessments based only on post-blast surveys can be strongly disputed.

In view of the conclusions reached herein, the following are recommended:

1. Introduction of the term "cracking" as a better descriptor of damage in the development of pertinent definitions.
2. Evaluation of the severity of cracking (or damage) with respect to aesthetic, engineering, and economic dimensions.
3. Finally, and perhaps most importantly, a judicial brief should be prepared under the auspices of the American Bar Association to define technical issues in blast induced cracking. Such a brief could serve to separate the technical aspects of cracking from annoyance.

Table 1

Summary of Direct Observational Studies on Blast Induced Cracking to Residential Structures

Investigator	Index	Damage			Material	Location of Monitor(s)	Source of Data
		Threshold	Location	Material			
Thoenen and Wudde, 1942	Ground Particle Acceleration	0.1g	NA	Plaster	Ground Surface near Structure	Monitoring of 6 homes excited by mechanical vibrators	
Crandell, 1949	Energy Ratio, ER	ER = 3 (3.3 ips)	Primarily Foundation Walls	NA	In Ground Near Structure	Pre-Blast and post-blast observations in over 1,000 structures subjected to vibration from construction and mining	
Langefors, Kihlstrom, and Hesterberg, 1958	Ground Particle Velocity	2.8 ips	Foundation Walls	NA	In Ground near structure	Data collected over an extensive period of time by monitoring structures subjected to vibration from construction blasts in rock.	
Edwards and Northwood, 1960	Ground Particle Velocity	4.5 ips	Super-structure Basement walls	Plaster Wallpaper Rubble-stone	Basement Walls	Monitoring of 6 structures during controlled blasting in glacial fill and silty sand.	
Dvorak, 1962	Ground Particle Velocity	0.4-1.2 ips	Super-structure	Brick and Masonry	Structure walls & in ground	Monitoring of 4 structures during controlled blasting in hard clay.	
Northwood, Crawford & Edwards, 1963	Ground Particle Velocity	4.0 ips	Super-structure Basement walls	Plaster Wallpaper Rubble-stone	Basement Walls	Monitoring of 6 structures during controlled blasting in rock and glacial till.	

Table 1 (Continued)

Investigator	Damage				Location of Monitor(s)	Source of Data
	Index	Threshold	Location	Material		
Crawford & Ward, 1965	Ground Particle Velocity	4.0 ips	Joints ----- Corners	Concrete Blockwall ----- Concrete Walls	Wall Exterior	Controlled blasting inside an 8 x 8 ft. sand filled box with poured concrete or block walls.
Wall, 1966	Ground Particle Velocity	0.04 to 0.12 ips	Super-structure	Concrete block walls	On ground surface in general area	Inspection of 41 houses before and after nuclear detonations at a distance of 33 to 78 Km.
Wiss & Nicholas, 1974	Ground Particle Velocity	7.0 ips	Super-structure	Gypsum Wallboard	In ground near structure and on walls	Pre-blast and post-blast inspections of one house and continuous monitoring of structural response during a series of ten blasts in glacial till.
Hondler et al., 1975	Ground Particle Velocity	3.5 to 4.3 ips	Super-structure	Plaster	On ground near structure and on walls	Pre-blast and post-blast inspection and continuous monitoring of 1 light weight concrete house subjected to 45 blasts in rock.
Bogdanoff, Larson and Nilsson, 1975	Ground Particle Velocity	8.0	Simulated Super-structure	Gypsum Drywall	On walls and on shake table	Testing of one room of standard construction on a biaxial shock test machine to simulate blast induced vibration.
Bergling, Eklund, & Sjoberg, 1977	Ground Particle Velocity	4.3 ips	Super-structure ----- Basement	Plaster Masonry ----- Joints ----- Concrete walls	On ground near structure end on walls	Pre-blast and post-blast inspection and continuous monitoring of 1 light weight concrete house subjected to 8 blasts in rock

Table 1 (Continued)

Investigator	Damage				Location of Monitor(s)	Source of Data
	Index	Threshold	Location	Material		
Esteves, 1978	Ground Particle Velocity	2.4 ips	Super-structure	Plaster	On ground and on walls	Monitoring of a house in the vicinity of a quarry with moving front.
Duvall and Fogelson, 1962.	Ground Particle Velocity	2.0 ips including safety factor				Statistical analysis of information from Thoenen and Winda, 1942; Langefors et al., 1958; Edwards and Northwood, 1960.
Devins, 1966	Ground Particle Velocity	2.0 ips including safety factor				Statistical analysis of information from Thoenen and Winda, 1942; Crandell, 1949; Langefors et al., 1958; Edwards and Northwood, 1960.
Nichols, Johnson and Duval, 1971	Ground Particle Velocity	2.0 ips including safety factor	Super-structure (new data)	Gypsum wallboard (new data)	In ground near structure and on walls	Statistical analysis of information flow; Thoenen and Winda, 1942; Langefors et al., 1958; Edwards and Northwood, 1960; and new data for one house from blast in glacial till.
Dowling, 1971	Response Spectrum	Damage bound				Response spectrum analysis of actual time histories obtained from Edwards and Northwood, 1960.
Medears, 1976	Pseudo Spectral Response Velocity					Comparison of PSRV and particle velocities with particle velocities measured by Edwards and Northwood, 1960, and Wias and Nicholls, 1974.

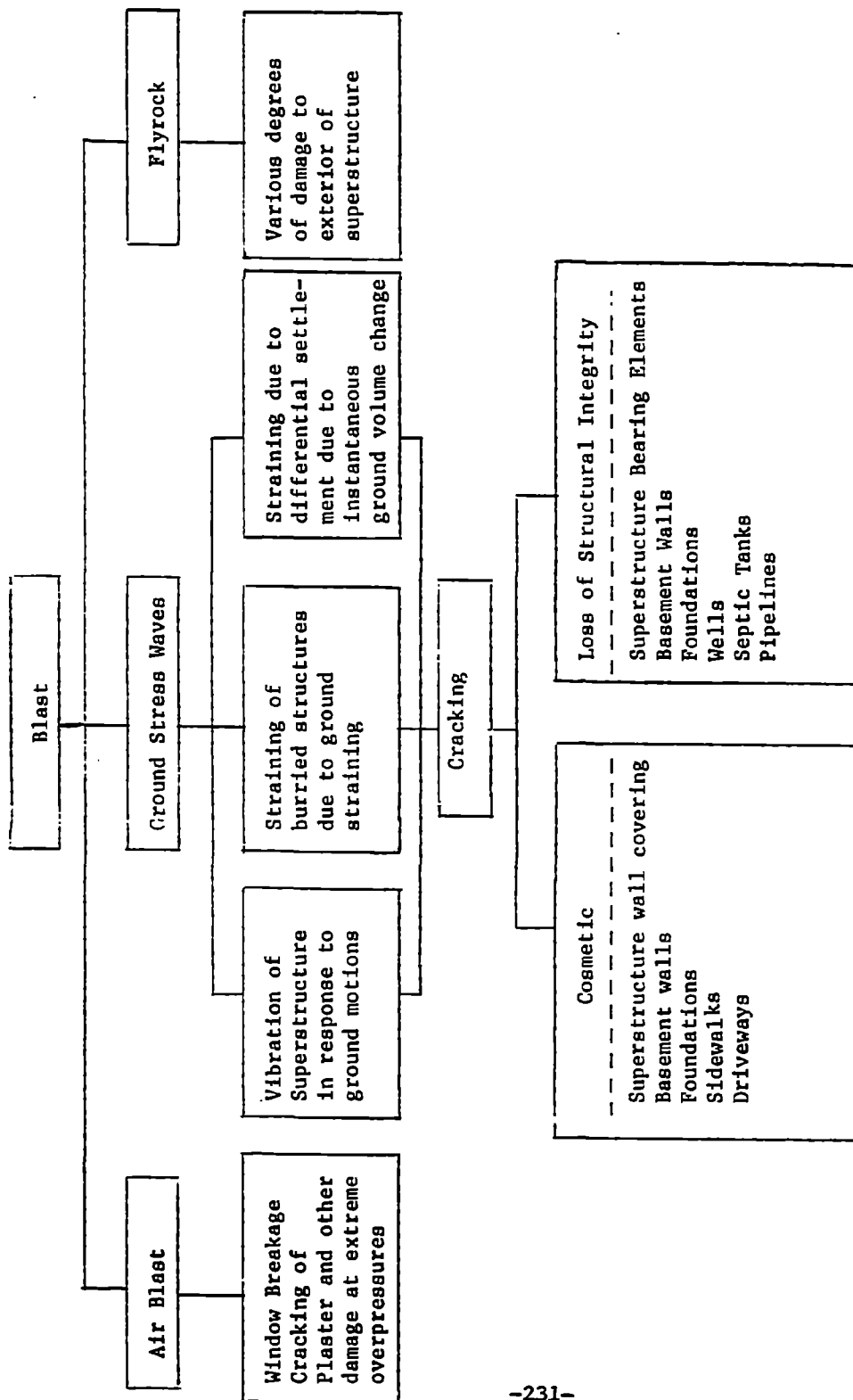


Table. 2 Types of Damage

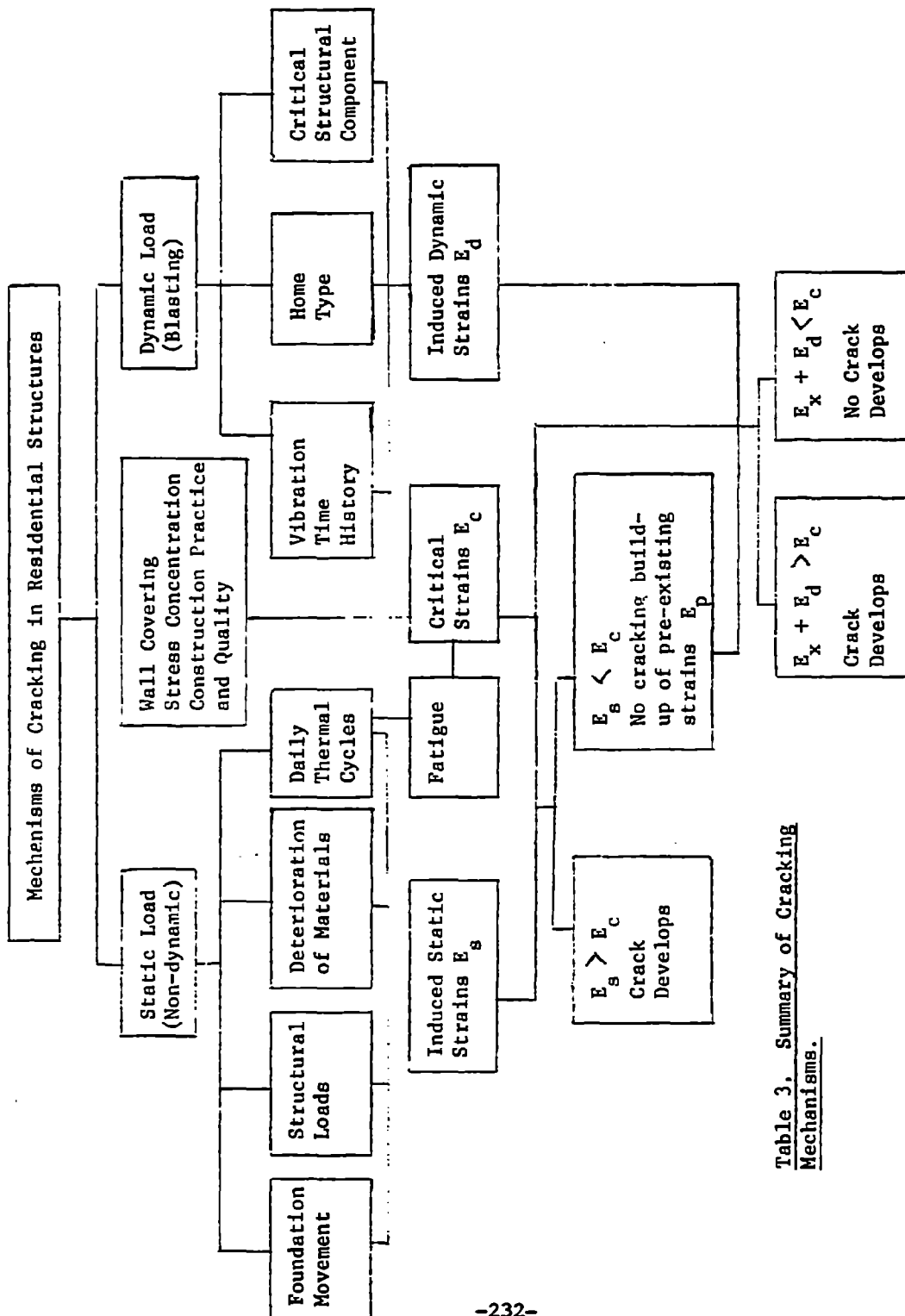


Table 3. Summary of Cracking Mechanisms.

PART SIX

BLAST RELATED ANNOYANCE

This report was prepared by George W. Kamperman of Kamperman Associates, Inc., under sub-contract to Center for Interdisciplinary Study of Science and Technology of Northwestern University, Evanston, Illinois.

I. INTRODUCTION

One possible impact on community from surface mine blasting is annoyance from air blasts and/or ground vibration. An overview analysis of studies relevant to blast induced annoyance was designed to provide information in the following areas:

- a. Procedures for predicting the magnitude of the air blast from scaled distance.
- b. Procedures for predicting the magnitude of the ground vibration from scaled distance.
- c. Methods for determining typical dwelling wall and floor vibration from the magnitude of an air blast.
- d. Methods for determining typical dwelling wall and floor vibration from scaled distance due to the ground wave and air blast.
- e. Correction factors for blasting configuration and sound propagation.
- f. Analysis and interpretation of recently available Bureau of Mines blast noise and vibration data.
- g. Methods for predicting people's annoyance to air blast.
- h. Methods for predicting people's annoyance from ground vibration due to blasting.
- i. Evaluate the impact of the above annoyance criteria versus currently "accepted" blast noise and vibration criteria.
- j. Documentation and references to support all of the above conclusions.

No study of human annoyance due to blasting has been carried out for either ground vibration or air blast. Studies on the annoyance of sonic booms is the best available information. Even though there have been many sonic boom studies, there are only two studies that have attempted to develop annoyance scales versus the magnitude of a sonic boom. There have been numerous studies on the human annoyance from vibration excitation. The vibration response studies have been quasi-continuous in their exposure or have lasted at least 1 to 5 minutes. There is only one limited study dealing with human response to impulsive vibration.

Based on the analysis presented below, a number of conclusions may be drawn.

1) People are far more annoyed by their house "rattling" than they are by the vibration they feel in the floor. This is true for both ground-borne vibration and air blasts.

2) Near a quarry or surface mine the magnitude of house vibration from a blast event is, on the average, the same from the ground vibration and the air blast at a scaled distance (ft/lbs^{1/2}) of 50. At greater scaled distances the air blast dominates and at smaller scaled distances the ground vibration

dominates the house vibration. If the house is downwind of the blast the house vibration will always be dominated by the air blast (except if the house is located behind a quarry face).

- 3) A house exposed to a parting shot in a mining operation will always be shaken more by the air blast versus the ground vibration.
- 4) The measurement of an air blast using C-weighted slow meter response correlates better than the peak over pressure with the resultant peak velocity of a dwelling wall exposed to the blast.
- 5) The relationship between peak over pressure and C-weighted slow meter response is identical for blasting in surface mines, quarries, and sonic booms.
- 6) A house wall facing the source of the air blast vibrates at a level three times greater than the house floor.
- 7) Blast noise or vibration cannot be related to annoyance on an energy basis such as L_{dn} used for aircraft, traffic, and other environmental noise. There appears to be a blast limit that people will tolerate and the number of blasts per day is of secondary importance. Indoor annoyance grows much more rapidly with increasing blast level than one would predict on a noise energy basis.

The rationale for the above conclusions are developed in the discussion which follows. The end product is a series of simple equations to calculate the magnitude of the various descriptors itemized at the beginning of the Introduction, plus graphs showing blast noise and vibration levels, and hypotheses concerning the estimated percent of the population that is very annoyed by blasting (if it is assumed blast produced air pressures are similar to sonic booms).*

II. COMMUNITY ANNOYANCE STUDIES WITH SONIC BOOMS

Relating community annoyance to the magnitude of blasting at quarries and surface mines is a problem that has never been given serious consideration. Between 1961 and 1972 extensive studies were made on the acceptance of sonic booms in both the U.S. and in Europe. Most of this work stopped in 1972 after the U.S. Government decided to ban sonic booms from commercial aircraft flying over the United States.

* If it is assumed that blast produced air pressures are similar to sonic booms, the following hypothetical estimates may be made. However, this is an assumption and should be treated as such until more definitive testing and analysis can be provided. (a) 10% of the population would be annoyed at 100 dBC (127 dB peak) air blast pressure; (b) 20% of the population would be annoyed at 103 dBC (128.5 dB peak) air blast pressure; (c) 40% of the population would be annoyed at 110 dBC (134 dB peak) air blast pressure; (d) 90% of the population would be annoyed at 115 dBC (138.5 dB peak) air blast pressure; (e) the above air pressures are often associated with ground particle velocity of 0.5, 0.64, 1.2 and 1.9 i.p.s. respectively.

Recently there has been renewed interest in understanding blasting impact from quarries and surface mines on the communities near these activities.¹⁻⁷ All of these studies were concerned with the air blast and the ground-borne vibration caused by blasting.

Blast noise and blast vibration limits have recently been proposed for surface mines and quarries.^{1,4} The most recent proposal is from the U.S. Department of the Interior, Office of Surface Mining (OSM). These recommendations appear in the Federal Register, Vol. 42, No. 239, December 13, 1977, and Vol. 43, No. 181, September 18, 1978.

This present analysis attempts to go one step further and predict the noise and vibration levels and the percentage of the population very annoyed by blasting at various levels of ground vibration and blast noise.

Several field studies have been carried out on people's acceptance of sonic booms in residential areas.⁸⁻¹⁵ In the United States the initial tests were conducted in St. Louis. The results of this test led to a much more extensive test on the annoyance of sonic booms at Oklahoma City. This was followed up by some very carefully controlled experiments at Edwards Air Force Base. Less ambitious programs were carried on in an additional half dozen U.S. cities. In Europe most of the work has been done in England and in France, with some work in Sweden.

Only the Oklahoma City and Edwards Air Force Base study contain sufficient objective and subjective data to generate an annoyance criteria versus the magnitude of a sonic boom. All the other studies do, however, provide useful qualitative information.

The largest data base is the Oklahoma City study⁹ conducted from February to July 1964. During this period the residents were subjected to an average of 8 sonic booms per day. The boom intensity was gradually increased throughout the program. Over 2,000 residents were personally interviewed with an extensive questionnaire. The first interview occurred one-third of the way through the program, the second two-thirds of the way through the program, and the last interview at the end of the program. Each of the 2,000 residents were interviewed all three times. As in other cities, the residents of Oklahoma City reported house "rattles" as the most annoying aspect of the sonic boom experience. The Oklahoma City residents, very annoyed with house rattles from sonic booms, is the best information available, and is considered very reliable. However, the sonic boom pressure range is rather limited and thus the annoyance range is also limited. The Oklahoma City data covered a range of 0 to 35% of the population very annoyed with house rattles. The only other published study that relates annoyance with higher sonic boom pressures was conducted at Edwards Air Force Base between June 1966 and January 1967.¹⁰

For the Edwards test, two Midwestern contemporary wood frame, single family dwellings were constructed at Edwards Air Force Base next to each other.¹⁵ One house was a single story ranch and the other a two story home. Both homes contained central air conditioning. During the actual tests, all exterior windows and doors were closed. The test subjects consisted of

approximately 100 residents of Edwards Air Force Base, who had previously been exposed to about 7 sonic booms per day for an average of about 2½ years. This group is of principal interest to this present study because of their previous acclimation to sonic booms and the fact that they were tested at a range of boom intensities significantly exceeding any other test results. Another test group of about 100 were residents from the California city of Fontana. These subjects are normally not exposed to aircraft noise except on rare occasions. The third group of about 150, were residents of Redlands, California. They had been rather accustomed to aircraft noise, but not sonic booms. These subjects were assigned to various indoor and outdoor test sites in or near the two specially constructed dwellings at Edwards Air Force Base. The aircraft sounds were presented in pairs with approximately 1 to 2 minutes between the members of each pair and a minimum of approximately 4 to 5 minutes between pairs. The subjects' main task was to indicate on an answer sheet which sound of each pair was the more acceptable if heard in or near their homes. They also were required to rate on a 13-point scale the acceptability of each of the sonic booms or sounds heard on certain days. The results of the Edwards test and the Oklahoma City study are discussed in detail later.

III. RELATING QUARRYING AND MINING BLAST DATA TO SONIC BOOM DATA

The sound energy spectrum of a sonic boom¹⁰ is very similar to a typical quarry or mining blast.³ The maximum energy is at very low frequencies (1 to 5 Hz) and the amplitude decreases approximately 6 dB per octave with increasing frequency. It has been shown that phase changes in the sonic boom wave front do not change the annoyance judgment of the boom. Annoyance is related to the total energy in the sonic boom.¹⁶

The risetime of a typical boom heard outside is 5 to 10 ms.¹⁵ The risetime of a typical quarry air blast is 10 to 100 ms with an average of about 50 ms, as measured outside.³ A very short risetime is extremely important in rating the loudness of a sonic boom as the perceived loudness increases as the risetime decreases below 10 ms.¹⁷ Sonic booms heard outside are far more annoying than quarry or mine blasts of the same peak pressure or acoustic energy because of the shorter risetime of the sonic boom.

Sonic booms and blasts of equal magnitude produce the same level of annoyance when heard inside a dwelling. The sonic boom risetime is no different than the blast risetime after entering a dwelling.^{15,18,19} The risetime inside a dwelling is always more than 20 ms whether it be from a blast or a sonic boom. The airblast from a quarry or mining blast event may last an average of 5 sec. with most of the energy produced during the first second followed by lower amplitude reflections.³ Sonic booms have a much shorter event, lasting from 0.1 sec. to 0.5 sec., depending on the size and speed of the aircraft.^{15,17-19}

IV. THE IMPULSE RESPONSE OF DWELLINGS

Houses, or dwellings, vibrate at their many natural frequencies whether excited by an air blast¹⁵⁻¹⁹ or ground vibration.^{2,20} The maximum acoustic energy in the ground wave or air wave at the dwelling resonant frequencies determines the magnitude of house vibration ("rattle"). Response spectra

of residential structures show typical homes to be 5% damped.²⁰ (A response spectrum may be defined as the curve represented by the locus of the maximum response values [displacement, velocity, or acceleration] of a single degree-of-freedom system, with or without damping, when subjected to an impulse forcing function, determined for various values of the system natural frequency.) Typical dwellings amplify the input vibration (at their natural or resonant frequencies) by a factor of two. In some cases the resonance amplification may be as much as five times.^{2,20} For the present study, it has been assumed that dwelling walls and floors will vibrate at the same amplitude as the resultant peak ground velocity outside the dwelling. The walls and floors in a typical dwelling have fundamental resonant frequencies between 10 and 20 Hz, and this is the frequency of greatest motion during a blast from both the ground-borne and air-borne impulse.^{3,7}

The ground signal from a blast contains very little energy below approximately 5 Hz.^{3,7} A typical dwelling does not respond at all to the high amplitude 1 to 2 Hz air blast.³ The structural system in a typical dwelling is also small compared to the wave length of sound at 1 to 2 Hz, and thus there is very inefficient acoustic coupling. It has also been observed that the low frequency sound pressure is the same inside and outside the dwelling during an air blast event, which suggests that the typical dwelling looks rather porous or open in the very low frequency range.³

The fact that typical single family dwellings do not respond to the very low 1 to 2 Hz frequency which represents the maximum energy in an air blast is a good reason for considering not measuring the very low frequency energy in the air blast when one is concerned with the physical response of typical dwellings. On the other hand, if one were studying blast noise impact on very large reinforced concrete structures, such as office buildings or dormitories, the maximum air blast energy in the 1 to 2 Hz frequency range would indeed be of interest as these very large structures have much lower resonant frequencies and more effectively couple to the acoustic wave because of their increased size. This present analysis is restricted to the physical response of typical, single family dwellings. Therefore, it would be desirable to measure the outdoor blast noise impact with a frequency weighting network that would have the same frequency response as the dwelling of interest. Attempts have been made to construct special filters for measuring blast noise to improve the correlation between the blast noise and the resultant dwelling vibration.^{3,7} No one filter response has been found that gives an outstanding correlation between measured air blast and typical dwelling vibration. This is not surprising because the impulse response of a house or dwelling is very complex. Furthermore, each air blast varies considerably in its detailed energy spectrum.³ The most important feature of an air blast filter is to eliminate the dominant low frequency energy below approximately 5 Hz as the typical dwelling does not respond to the intense low frequency energy below 5 Hz.

This analysis was fortunate to be supplied Table 3 of Reference 7 of the Bureau of Mines. Although this was the only information from the Bureau of Mines study that could be made available to this analysis, it proved to be very beneficial. The Bureau of Mines data contained simultaneous measurement of the air blast peak over pressure, the C-weight slow meter response,

and the resultant peak velocity of a dwelling wall impacted by the air blast. Most of the measurements were made at surface mines, including parting shots, with the remaining data from stone quarries. The house wall vibration produced by the same air blast are shown in Figs. 1 and 2. Figure 1 is a correlation of the peak sound over pressure (0.1 Hz to 10,000 Hz) to the peak velocity of the dwelling wall impacted by the air blast. The linear regression line in Figure 1 has a correlation coefficient of .56. The C-weighted slow meter response of the same blast noise is plotted in Figure 2, against peak dwelling wall velocity. The linear regression line in Figure 2 utilizing the standard C-weighted slow meter response has a correlation coefficient of .76, which is significantly better than the correlation determined from Figure 1. If the dwelling wall vibrated in a linear manner (double wall velocity for double sound pressure), one would expect a unity slope as shown as the dashed line in Figure 2. However, as the wall excitation increases, the damping properties in the wall also increase, thus, the measured slope is probably realistic. The test results of Figure 1 and Figure 2 lead to the conclusion that the standard C-weight slow response should be used for this study to evaluate blast noise.^{2-4,21}

ANSI 1.4-1971 specifies the frequency response of the C-weighted network for a standard precision sound level meter over a wide frequency range starting at 10 Hz at the low end. It is the only standardized frequency weighting network that correlates fairly well the measured blast noise and resulting wall velocity in typical dwellings. Further research studies on the response of structures to blast noise should certainly consider more than the C-weighted slow response of a sound level meter for measuring the blast noise. For any additional studies, it is recommended that the sound measuring system tape record the entire time history of the blast event. The entire recording and reproduction system, including the microphone, should have a uniform frequency response extending from 0.1 Hz to approximately 500 Hz. Air blasts recorded in this manner will permit detailed analysis in both the time domain and frequency domain. From similar studies^{3,7} it was concluded that C-weighted slow meter response or the C-weighted sound energy (CSEL) were adequate blast noise descriptors for monitoring and enforcement purposes. It has been argued that a true integration of the C-weighted sound energy, CSEL, over an entire blast event would be a better descriptor of the energy shaking the house. This is probably true. Quarry³ and mine blasts produce the most blast noise energy during the first second,³ so C-weight slow meter response or CSEL are equal. In some situations, a significant amount of air blast energy extends over several seconds due to reflections and different sound propagation paths. For these situations, CSEL would read 1 to 3 dB above C-weighted slow meter response. The reason for this is that CSEL integrates the C-weighted sound energy over the entire event and normalizes it to the equivalent energy over a 1 sec. period, and C-weight slow meter response has a simple 1 sec. resistor-capacitor integration time. Therefore, for impulse events lasting 1 sec. or less, such as sonic booms, CSEL and C-weighted slow meter response are always equal.

The dwelling wall facing the source of the blast will vibrate more than the other walls in a dwelling.⁷ The dwelling floors will vibrate 1/3 (10 dB down) as much as the wall facing the source of the blast.³

V. RELATIONSHIP BETWEEN AIR BLAST PEAK OVER PRESSURE AND C-WEIGHTED SOUND LEVEL WITH SLOW METER RESPONSE

Measuring the true peak sound pressure of an air blast from a mine or quarry (or sonic boom) requires special instrumentation with extended low frequency response (down to 0.1 Hz). The current blast monitoring instrumentation used in the field cannot accurately measure the 1 Hz peak associated with an air blast. The proposed blasting limits from OSM further complicates the picture by permitting the use of measurement systems with four different frequency weighting characteristics. It is recommended that OSM adopt ANSI S1.4-1971 specifications for a precision sound level meter set for C-weighting slow meter response, CSEL, or alternative systems that record air pressures at frequencies associated with house "rattle". The cost of the precision sound level meter meeting the ANSI standard could be greatly reduced if the instrument were required to meet the precision sound level meter standard over the frequency range from 10 Hz to 1,000 Hz. To permit blast noise measurements for monitoring or enforcement with a measuring system with a low frequency roll-off of 6 Hz, 2 Hz or some other frequency, without requiring the measuring instrumentation to meet a rigorous performance specification is likely to lead to chaos. It is not difficult to envision two non-standard instruments from different manufacturers with identical low frequency cut-off, giving measured results 20 dB apart.

All the useful sonic boom studies were conducted with sound measuring instrumentation capable of correctly measuring the true peak over pressure. Two quarrying and mining blast studies were recently completed that also correctly measured the air blast peak pressure, C-weighted slow meter response, and CSEL.^{3,7} Figure 3 shows the measured difference between the true peak sound pressure level and the C-weighted slow sound level for sonic booms and blasting. The Bureau of Mines data⁷ represents 100 data points (10 quarry and 90 surface mines), with a correlation coefficient of .88. A regression line through the data from Reference 3 agrees exactly with the Bureau of Mines, with a correlation coefficient of .9. The surface mining parting shots were separated out in the Bureau of Mines data and are shown in Figure 3. For a given peak over pressure, a parting shot contains twice the house shaking energy (6 dB). This is one more important reason for monitoring air blasts with an instrument having C-weighted slow response or CSEL.

The sonic boom data obtained at Edwards Air Force Base was recently re-evaluated to determine the relationship between peak over pressure and CSEL (the same as C-weighted slow meter response, in this case).²² The two short regression lines straddling the quarry and surface mine data are the sonic boom results. The agreement is better than one could have hoped for. These results further suggest that sonic booms are very similar to quarry and mine blasts. There is not a constant difference between peak over pressure and C-weighted slow meter response because of a gradual upward shift in the energy spectrum with increasing peak over pressure.

VI. BLAST NOISE AND VIBRATION EXPOSURE TO NEARBY DWELLINGS

For years it has been common practice to predict ground vibration at a distance from a blast event using a scaled distance formula relating

charge weight per delay to the estimated ground velocity at a specific distance. Reference 6 contains a large body of data on ground velocity measurements for blasting at quarries, mines and construction sites. Figure 4 gives the mean resultant ground velocity versus scaled distance for mines and quarries. The data on construction blasting is very similar to the results for quarry blasting. One standard deviation on the data is almost a factor of two in velocity, which is more than the difference between the mining and quarrying regression lines in Figure 4. The ground velocity versus scaled distance in Reference 20 agrees well with the results in Figure 4. The mean or L50 regression lines shown in Figure 4 will be used as part of the prediction model. It should be kept in mind that at least 5% of the blasts should be expected to result in ground vibration three times (10 dB) higher than that indicated in Figure 4.

Estimating the air blast at a distance is far more difficult because of the strong influence the local weather conditions have on sound propagation, face orientation in a quarry with respect to the receiver, sound reflections, and occasional blowouts. For this present study, long delayed sound reflections because of abnormal weather and blowouts are not considered because of insufficient data. The only published study to date concerned with local weather influence on quarry and mine blast noise propagation is in Reference 3. Figure 5 represents the best estimate available on blast noise level versus scaled distance. The blast data contained in References 6 and 7 are of less value because there is no correlation with wind direction. The principal shortcoming of the data in Figure 5 is that all data was measured around stone quarries. The coal mine blast data in Reference 7 was plotted to show scaled distance versus the C-weighted slow meter response. Of the 50-some data points, one dozen consecutive shots, all measured at one mine at approximately the same distance, were approximately 10 dB below all the other data. A regression line through the remaining data matches the middle regression line in Figure 5 within a fraction of a decibel. Reference 7 contains data on two dozen parting shots in coal mines. Plotting these data points on Figure 6 gives a regression line with almost no slope and less than .2 correlation coefficient. Parting shots are much more difficult to control and contain, and thus one would expect considerable scatter in the data. To be able to use the parting shot data, the generalized slope from Figure 5 of -15 dB per 109 cycle was applied to the data in Figure 6.

The air blast data shown in Figures 5 and 6 were compared against the measurements in Figure 2 to arrive at an estimate of the typical dwelling wall velocity caused by an air blast versus the scaled distance. Table 1 discusses how to add correction factors to Figure 7 (or Figure 4) to take into account weather conditions and different types of blasts. A review of Table 1 and Figure 4 clearly shows that the air blast can often be the dominant factor in vibrating a residence. It should be remembered that the estimates of wall velocity due to an air blast are based on measurements of typical dwelling walls that were facing the source of the air blast.³ The Bureau of Mines measurements⁷ indicate that the magnitude of the air blast directly in front of a quarry face may be 2 to 4 times greater than that shown in Table 1 and Figure 7 for scaled distances less than 100. This discrepancy should be resolved when the Bureau of Mines report⁷ is published. At the present time, the topography, weather conditions, and type of blast are not available.

It has been common practice to consider ground velocity versus scaled distance in terms of distance in feet divided by the square root of the charge weight per delay. It has also been conventional practice to consider blast noise with a scaled distance based on the distance in feet divided by the cube root of the charge weight per delay. Linear regression analysis was performed on all of the air blast data using both the square root of the charge weight per delay and the cube root of the charge weight per delay. There did not appear to be a statistical significance in the differences in the correlation coefficients for either method. Therefore, the square root law was used both for ground vibration and air blast to permit easy comparison, as shown in Figure 4.

VII. ESTIMATE OF COMMUNITY ANNOYANCE FROM BLASTING

The previous sections have concentrated on the physical impact or response of a typical dwelling to production blasting in a quarry or surface mine. The physical descriptors of ground vibration and air blast can be translated into terms of human annoyance of the residents subjected to blasting activities by utilizing the extensive community studies of annoyance from sonic booms produced by aircraft overflights.

The Oklahoma City sonic boom study⁹ is considered by most researchers in this field to be very realistic, and probably the most reliable data available. Approximately eight sonic booms occurred each day during daytime hours over a six-month period. Two thousand residents were interviewed in depth at three different periods throughout the six-month test. The interviews and the sonic boom exposures were sufficiently comprehensive to permit many different types of comparisons with the sonic boom exposure. The reported annoyance with sonic booms, reproduced in Table 2, appeared to be the most appropriate for the present study. Clearly, house rattles caused the greatest annoyance. People were often annoyed by several things, including house rattles, startle, and interruption of sleep or rest. However, it was found that if anyone was annoyed, they were always annoyed by house rattles. For this analysis, the category of "very annoyed with house rattles" was selected to be most appropriate to people's annoyance with blasting. Table 3 shows the outdoor sonic boom noise exposure versus the percent of the population very annoyed with house rattles. The C-weighted slow meter response (dBC) was derived from Figure 3.

The data from Tables 2 and 3 are shown in Figure 8. The linear regression line has a correlation coefficient of .96. Plotting the percent of the population very annoyed with house rattles against peak over pressure (psf) gave a correlation coefficient of .98. Thus, plotting the percent of very annoyed against either a linear or logarithmic pressure scale gave essentially the same correlation coefficient. This has led several investigators to the conclusion that sonic booms and blast noise can be treated on a sound energy basis.^{4,21,23} With this equal energy argument, one would look at the Oklahoma City data in Figure 8 based on eight sonic booms per day and say that one boom or one blast per day could be 9dBC (10 log 8) higher in amplitude for the same percent of population very annoyed as shown in Figure 8. However, this would seem to be an incorrect assumption. While it can be agreed that as one reduces the number of booms or blasts per day, the annoyance will also be reduced, unfortunately, little attention has been given to relating annoyance to the number of booms or blasts per day. One study in England²⁴ called Exercise Yellowhammer, concluded that increasing the number of bangs per day is closely equal in annoyance

to doubling (6 dB) the peak sound pressure. These tests were conducted with explosive charges ranging from 1/2 to 7-1/2 lbs. suspended several hundred feet above the ground. The results of this test would tend to support the equal energy concept which would result in a 5 dB difference for a 3 to 1 change in blast events of equal intensity. However, these results can be interpreted to suggest instead that the population was reacting to the loudness produced by the very short risetime of a 2 lb. charge exploded above the ground. The English study showed that a dwelling did not respond nearly as much to the explosive charge as it did to a sonic boom having the same peak over pressure. An equal energy trade-off for small explosive charges detonated above the ground, such as gun clubs or army artillery ranges, may be very appropriate, but is not necessarily applicable to mine and quarry blasting.

There are urban quarry operators who are very concerned with good neighbor relations and therefore design their blasting configurations to hold the resultant peak velocity at the nearest residence within 0.2 in/sec. They use this same criteria whether they blast once per week or five times per day. Similarly, there are larger surface coal mine operators who have internal policies of limiting their blasting levels ranging from 0.4 for some companies to as high as 1 in/sec resultant peak velocity at the nearest residence. Again, this is irrespective of the number of blasts per day or per week. Obviously, these quarry and mine operators have made a conscious decision to limit their blast levels based on their own experience. Clearly, community pressure has helped formulate these internal company guidelines. It is also not surprising to see that stone quarries seem to have generally established lower blast limits than surface coal mines, as the nearest dwelling adjacent to quarry blasting activity is typically the nearest dwelling for many more years than the nearest dwelling adjacent to surface mine blasting activity. Blasting at the industry accepted limit of 2 in/sec at the nearest occupied dwelling was not even considered by many responsible mine and quarry operators, even though there was no cost benefit derived by blasting at levels below 2 in/sec. The reasons the companies have selected the lower level blasting criteria will become apparent as the annoyance scales are developed.

The Oklahoma City sonic boom study results shown in Figure 8 are reproduced unchanged in Figure 9. It is assumed that residents inside typical single family dwellings would register the same annoyance from an air blast as from a sonic boom, provided they both had the same sound level (C-weighted slow response) measured directly outside the dwelling. This subject will be addressed in more detail later. The ground velocity equivalent to the air blast sound level shown in Figure 9, was derived from the information in Figure 2 and is based on an assumption that the house, floor and wall vibrations will be equal to the resultant ground velocity measured immediately outside the dwelling of interest.^{2,3} The dwelling will amplify the ground vibration at its various resonant frequencies, however, on a statistical basis, the wall and floor peak velocities are only slightly greater than the peak resultant velocity measured in the ground immediately adjacent to the dwelling.^{3,7}

Figure 9 is based on the assumption that there are eight sonic booms or eight blasts per day. One might expect that the percent of the population very annoyed by blasting at a specific level would be less annoyed if the number of blasts per day were reduced from eight to one per day. Unfortunately, there exists no quantitative data to determine how much reduction, if any, in the percent

of the population very annoyed, would occur if the number of blasts per day were reduced from eight to one per day. The CHABA guidelines⁴ recommend the equal energy concept for blasting. Under the equal energy concept, a quarry or surface mine operator that has regularly been blasting eight times per day at a given level, could reduce the number of blasts to one per day and simultaneously increase the intensity of that blast eight times, and expect the same annoyance from the residents as the previous eight smaller blasts per day produced. It is quite doubtful that one could find any knowledgeable quarry or surface mine operators who would agree with this assumption. Conversations with many residents continually exposed to production blasting indicates that they remember most vividly the particular blasts that are more intense than the average blast. Typical statements are in the tone: "You should have been here the other day; the blasts today are nothing in comparison."*

The Edwards Air Force Base sonic boom tests can be interpreted to further support the argument that annoyance with blasting is a non-linear phenomenon. It should also be remembered that all sonic boom studies have shown house rattling to be the most annoying aspect of the sonic boom. House rattling is non-linear and one might expect a rapid growth in the percent of very annoyed people as the intensity of the house rattling increases.

For the sonic boom tests at Edwards Air Force Base, two typical contemporary Mid-west single family, wood frame dwelling were constructed next to each other.¹⁵ Three groups of subjects were used for the subjective tests, as noted earlier in Section II of this report. One group of about 100 residents that lived on the Base had been exposed to about seven sonic booms per day for an average over the past 2½ years. The information obtained from this group is most pertinent to the current study. The sonic boom tests were conducted between June 1966 and January 1967 at Edwards Air Force Base. The results of the sonic boom tests are shown in Tables 4 and 5. These tables are from Reference 10. The C-weighted slow meter response sound level from Figure 3 has been added to the tables. E1 is a single story home. E2 is a two story home. The two letter designations under E1 and E2 represent the different listening rooms in each house.

The sonic boom data from Tables 4 and 5 are plotted in Figure 10. The aircraft sonic booms were presented in pairs with approximately 1 to 2 minutes between the members of each pair, and a minimum of approximately 4 to 5 minutes between pairs. Each experimental test condition was repeated four times, twice with sound A or the pair given first in the sequence and twice with sound B of the pair given first. The subjects were asked to note which sound of each pair was the more acceptable if heard in or near their homes. They were also required to rate on a 13-point scale the acceptability of each of the sonic booms. The title at the beginning of the scale was "Very Acceptable", at the center of the scale, "Just Acceptable", and at the far end of the scale, "Unacceptable". Figure 10 shows the percent of the subjects that judged the sonic booms unacceptable (less than just acceptable). The Edwards data are divided into two groups; less than 40% judged unacceptable and greater than 30% judged unacceptable. The solid lines are the linear regression

* The above statements are based on professional field observations of Kamperman Associates, Inc.

results for the indoor data. The long dashed lines represent the results from the outdoor subjects. The short dashed line is the result from the Oklahoma City study shown in Figure 8. The "F" shown in the center of Figure 10 are the results from the residents living in Fontana, California, who are not normally subjected to aircraft noise or sonic booms. The "R" at 29% unacceptable represents the subjects from Redlands, California, who have had considerable previous exposure to aircraft noise, but not sonic booms. Only the indoor results are shown for the Fontana and Redlands subjects.

It is interesting to note that the Edwards Air Force Base residents judged the outdoor sonic boom unacceptable to within 1 dB of what Oklahoma City residents judged house rattling very annoying. The correlation coefficient for the Air Force Base residents measured inside was not as good ($r=.71$), but the results still ranged from 0 to 3 dB more tolerant of sonic booms than the citizens of Oklahoma City.

That the above 40% judged unacceptable results (indoor and outdoor) are so close is likely a fortuitous result. The outdoor subjects are strongly influenced by the sharp crack(s) heard with the boom due to the very short risetime of less than 10 ms.^{15,17} The risetime on a quarry or surface mine blast ranges from 10 to over 100 ms., with an average around 50 ms.³ The subjects inside the house do not experience a risetime shorter than approximately 50 ms from a sonic boom, quarry or surface mine blast, because of the high frequency attenuation of the dwelling.^{3,7,8,19} It should also be remembered that all exterior doors and windows were closed during the sonic boom tests.

The Edwards tests showed that the outdoor sonic boom was judged by 46% of the subjects to be unacceptable, while the same boom was judged unacceptable by 70% of the subjects in the dining room of the two story house, yet the measured effective perceived noise level (EPNdB) inside the dining room was 20 EPNdB below that measured outside.¹⁰ The subjects inside the houses did not hear the sonic boom. They heard only the response of the house to the boom impulse. Only the Edwards study found the boom to be less acceptable outdoor versus indoor.^{8,10,31} This is understandable as the lower amplitude booms used in Oklahoma City, St. Louis, and other localities did not have the very short risetime accompanying the higher amplitude booms shown in Figure 10.

There is one data point omitted on each of the two regression lines above the 30% judged unacceptable. The B70 data point was omitted from the indoor judgments. To have included the data point would have further increased the steepness of the indoor slope. The F-104 data point, outdoor at 75% unacceptable, was omitted because it represented only one test and would have made the outdoor condition even less acceptable for a given sound level.

The Edwards Air Force Base tests were conducted with an average of eight sonic booms per day. Closer observation of the actual flight schedules revealed that the booms per day ranged from 1 to 10.^{10,17} Many days had only 3 booms and the entire test was over in 10 minutes. Even in the case where there were 17 booms in one day, this was all accomplished in a period of 2-1/2 hours. All data points in Figure 10 above 30% unacceptable were arrived at from tests conducted on different days. The highest indoor data point was judged to be unacceptable by 82% of the subjects. On that test day there were 8 booms, all

within a 1/2 hour period. Half of them were at the intensity shown and the other half were at an equivalent pressure of 106 dBC. This lower level would be judged only 27% unacceptable. Sonic boom tests were conducted on 2 consecutive days to determine the unacceptability of boom over pressures equivalent to 106.1 dBC. On the first day there were 17 consecutive booms over a period of 2-1/2 hours. On the second day, there were 14 consecutive booms over a period of 5 hours. B-58 and F-104 aircraft were used both days, flying at various altitudes and speeds to create different sonic boom over pressures. The example cited above clearly illustrates that the unacceptability of sonic booms is related only to the magnitude of the boom over pressure (C-weight, slow response) and not the number of sonic booms per day.

The results of the Oklahoma City study and the Edwards Air Force Base study where subjects indoor were exposed to intense sonic booms, is summarized in Figure 11. It is recommended that Figure 11 be used for estimating the percent of the residents very annoyed by the air wave associated with blasting. For any given level of blasting, it is estimated that the percent of the population that is very annoyed will remain essentially the same, whether there be one or eight blasts per day.

The Edwards program included judging the response of subjects (inside and outside) subjected to sonic boom while they were vibration isolated from the floor or ground. The vibration isolation consisted of a plywood platform resting on soft, inflated rubber tubes. They found no statistical difference in the subjective judgment of unacceptability of the sonic booms, whether the subjects were vibration isolated or exposed to the vibration in the floor or ground.¹⁰ The subjects responded to what they heard and not the vibration transmitted through their chairs. The same phenomenon is expected to be true for blasting. It is probable that if subjective tests were conducted simultaneously inside and outside of homes during typical blasting events, the results would show that the subjects inside the homes would rate the blast experience far more annoying than would the subjects outside.

Several studies²⁷⁻²⁹ have shown that sonic booms recorded with a system having a uniform frequency response to 0.1 Hz to 10,000 Hz can be reproduced faithfully in the laboratory. It was found that the subjective annoyance does not change if the energy below 40 Hz is omitted from the sonic boom. This is an additional reason for utilizing the C-weighted network for measuring sonic booms as the low frequency response rolls off at 30 Hz. The contention here is that people are more annoyed by house rattle and startle than the vibration they feel in the floor. There²⁵ is at least one study that deals with human sensitivity to impulsive vibration. Most studies of human response to vibration have subjected people to the vibration for durations of 1 minute or longer.

The experimental results from Reference 25 are shown in Figure 12. Peak velocity is plotted against exposure time. The exposure times shown are for a 1 sec impulse, a 5 sec steady state exposure, and a 5 minute (300 sec) steady state exposure. The solid lines connect the data points judged "Strongly Perceptible." The dashed lines connect the data points judged "Distinctly Perceptible." The 5 minute test also had data on vibration levels judged "Disturbing." As an example, assume a dwelling is exposed to a quarry blast. The dwelling floor has a resonant

frequency of 10 Hz and 5 to 10% damping. For a resultant peak velocity of 0.5 in/sec in the ground next to the dwelling (and the same in the dwelling floor), the estimated percent of the residents very annoyed would be 12% (from Table 6 or Figure 9). Figure 12 shows that this example falls in the center of the 1 sec circle for "Distinctly Perceptible," which is well below "Strongly Perceptible." A second example would be to select an impulse of 1.25 in/sec, the "Strongly Perceptible" 1 sec impulse in Figure 12. Forty-four percent of the population are estimated to be very annoyed from a blast at this level (Table 6). Although the level of floor vibration is not "Disturbing," over 40% of the residents are very annoyed by house rattles.

VIII. IMPACT OF PROPOSED ANNOYANCE CRITERIA VERSUS OSM AND CHABA CRITERIA FOR BLASTING

The office of Surface Mines(OSM) has proposed blast noise and ground vibration limits for blasting.²⁷ The final limits that are established by OSM are extremely important to all parties concerned with blasting. The OSM blast noise and vibration limits will become a nationwide regulation. The CHABA criteria⁴ for blast noise and vibration are of interest because their purpose is to establish guidelines for assessing environmental impact. There is currently a²⁸ revision being considered by CHABA for determining human annoyance to blast noise. In this present report, annoyance scales have been developed for blasting. Various blast noise levels are compared with the above criteria in Table 7. Ground vibration at a residence is compared to different vibration criteria in Table 8. The equations in Table 6 may be used to determine additional annoyance values for data not shown in Tables 7 and 8.

The correlation between the percent of people very annoyed and the percent of people that will complain about a blast¹⁸ event is a very complex problem, as demonstrated in the Oklahoma City boom study. Some studies have shown that complaints start when 20% of the population is very annoyed, while others argue that the percent of the population²³ that complain is closely related to the percent of the population very annoyed.

The CHABA criteria in Table 7 appears to underestimate the annoyance, at least during daytime. The modified CHABA criteria that is now under consideration appears to be more realistic. The CHABA percent annoyed in Table 7 was arrived at by estimating CSEL by arbitrarily adding 2 dB to the dBC slow meter response value. The CSEL was then converted to the 24 hour L_{cdn} as recommended by CHABA by subtracting 49.4 dB from CSEL (10 log x the number of seconds in 24 hours).

The CHABA recommendations or the modified CHABA recommendations show that blasting during nighttime will approximately double the percent of the population very annoyed for the same blast level during daytime. The sonic boom studies were conducted during daytime hours and thus it is not possible to estimate the increase in the percent that would be very annoyed for blasts during nighttime hours. Some very limited laboratory experiments have been conducted on the interference of sleep when a person is subjected to a sonic boom. There just isn't sufficient data to assist this present analysis. The CHABA position that the percent of the population very annoyed doubles for a given blast during nighttime versus daytime appears to be a reasonable assumption.

Table 8 shows the anticipated annoyance versus ground vibration during a blast event. The CHABA criteria are reported to be based on less than 1% complaints from the community exposed to the levels shown. The CHABA blast levels appear to be very conservative, and a nighttime reduction of 10 to 1 is certainly very conservative.

IX. CONCLUSIONS

This analysis was undertaken to develop a model for predicting ground vibration and air blast levels at various distances from blast events in surface mines and quarries. After determining the vibration and air blast exposure to residential areas, it is desirable to predict the probable percent of the impacted residents that are very annoyed by the blasting. Table 6 summarizes the various prediction equations to arrive at the blast impact on residents.

This analysis has made no attempt to correlate the percent very annoyed with expected percent of complaints. This is a very complex subject in itself.¹⁸

This analysis has concluded that blast noise and ground vibration cannot be treated on an equal energy basis for trade-off between the number of blast events versus the magnitude of the blast. For example, reducing the number of blasts per day from 4 to 1 does not mean that that single blast intensity can be increased fourfold and expect the same annoyance produced by the 4 smaller blasts. Determination of the relationship between blast intensity, number of blasts and annoyance will require further controlled testing.

The blast noise descriptor selected was C-weighted slow meter response as read from a precision sound level meter as this correlated with typical single family dwelling wall motion better than peak over pressure. There is no information available to tell whether C-weight slow response or CSEL correlates better with annoyance from blasting.

Sound propagation of blast noise has been only grossly estimated in this report because it is not possible to be more precise.³²

Table 1. Correction Factors for Air Blast in Figure 7.

Wall Velocity from Air Blast versus Scale Distance

1. Lapse weather condition - no correction.
 - a. Sun and no wind.
 - b. Sun or clouds, > 5 mph cross wind or up-wind of source or down-wind behind a quarry face.
2. Down-wind from mine pit or quarry face, 3 times estimated levels (10 dB).
3. Up-wind or cross-wind behind quarry face, reduce estimated levels to 1/4 (-12 dB).
4. For parting shots in an open pit mine (lapse weather condition) estimate by 4 (12 dB). If receiver is down-wind, increase estimate by 10 (20 dB).
5. Weather conditions causing a temperature inversion or sound focusing, expect above lapse weather condition estimated levels to increase by 2-4 (6-12 dB), 1/2 mi. from source and by 10 (20 dB) at distances greater than approximately 1 mi.

Table 2

REPORTED ANNOYANCE WITH SONIC BOOKS
BY TYPE OF INTERFERENCE AND DISTANCE FROM GROUND TRACK

Oklahoma City Area
February-July 1964

	Total	Distance from Ground Track											
		0-8		8-12		12-16		16-20					
Type of Interference and Intensity of Annoyance		2/3	4/20	6/15	2/3	4/20	6/15	2/3	4/20	6/15	2/3	4/20	6/15
Number of Respondents	2019	2026	1915	1037	1045	989	351	331	336	335	336	335	314
House rattles-Total	54.3%	66.0%	73.1%	54.3%	68.2%	74.8%	56.6%	55.3%	67.7%	46.2%	56.7%	60.6%	60.6%
Very annoyed	15.4	24.4	32.8	16.6	25.9	35.3	12.5	19.4	25.4	5.1	11.0	16.9	16.9
Moderately annoyed	17.7	19.6	20.7	17.8	20.3	20.6	17.9	16.8	20.8	14.6	19.7	18.5	18.5
Little annoyed	21.2	22.0	19.6	19.9	22.0	18.9	26.2	19.1	21.5	26.5	26.0	25.2	25.2
Startles-Total	30.0%	31.1%	35.4%	30.6%	32.2%	37.0%	28.4%	26.7%	29.1%	20.3%	21.3%	22.3%	22.3%
Very annoyed	9.2	12.0	16.1	9.8	12.5	16.8	7.1	9.1	12.7	3.3	4.5	7.6	7.6
Moderately annoyed	10.3	9.8	11.6	10.5	10.1	12.6	10.5	9.1	7.3	5.4	8.4	8.6	8.6
Little annoyed	10.5	9.3	7.7	10.3	9.6	7.6	10.8	8.5	9.1	11.6	8.4	6.1	6.1
Interrupts Sleep-Total	12.0%	13.1%	16.2%	12.7%	14.9%	17.5%	10.8%	6.0%	10.2%	4.8%	7.5%	8.3%	8.3%
Very annoyed	4.9	6.7	9.2	5.2	7.3	9.9	4.6	4.0	5.7	1.2	2.1	4.5	4.5
Moderately annoyed	3.7	3.9	4.9	4.1	4.6	5.6	3.1	1.4	1.8	1.5	3.3	2.2	2.2
Little annoyed	3.4	2.5	2.1	3.4	3.0	2.0	3.1	.6	2.7	2.1	2.1	1.6	1.6
Interrupts Rest-Total	9.7%	12.2%	16.6%	10.1%	12.0%	17.7%	9.4%	10.0%	13.6%	4.8%	6.6%	8.6%	8.6%
Very annoyed	5.2	6.8	10.6	5.3	6.9	11.5	4.3	6.0	8.2	1.8	3.3	5.1	5.1
Moderately annoyed	2.8	3.8	3.8	3.1	4.0	3.8	2.8	3.7	2.7	2.4	2.1	2.5	2.5
Little annoyed	1.7	1.6	2.2	1.7	1.9	2.4	2.3	.3	2.7	.6	1.2	1.0	1.0

Table 3. Median Sonic Boom Overpressures (psf), C-Wt, Slow (dBC) and Percent Very Annoyed with House Rattles, by Distance from Ground Track

Oklahoma City Area February-July 1964											
Miles from Ground Track .											
Time Period	No. Weeks	0-8			8-12			12-16			
		%	psf	dBC	%	psf	dBC	%	psf	dBC	
Feb. 3- Apr. 9	11	16.6	1.13	103.1	12.5	0.80	99.5	5.1	0.65	97.4	
Apr. 20- June 14	8	25.9	1.23	104.0	19.4	1.10	102.9	11.0	0.85	100.2	
June 15- July 25	6	35.3	1.60	106.8	25.4	1.35	105.0	16.9	1.00	100.9	

Table 4

PERCENTAGE OF PERSONS WHO RATED SONIC BOOMS AND NOISES AS UNACCEPTABLE (LESS THAN JUST ACCEPTABLE) LISTENERS FROM EDWARDS AIR FORCE BASE

A/C	SOURCES OF BOOMS AND NOISES				LOCATIONS OF PERSONS											
	Overpressure (psf) dBC	All.	EPR	PNGB	Number of Missions	Out-door	Block-house	In-door	E1&E2	E1-BR	E1-LR	E1-FK	E2-BR	E2-LR	E2-DR	E2-FK
B-58	1.69	107.3			12	33%	23%	27%	15%	25%	17%	39%	46%	28%	24%	
B-58	2.06	109.3			4	51	--	37	42	68	20	11	28	73	54	
B-58	2.33	110.6			11	63	--	28	34	44	6	13	61	38	39	
B-58	2.62	111.4			2	64	--	49	41	67	32	18	83	92	40	
B-58	2.65	111.9			8	58	55	62	32	70	62	89	73	56	59	
	Av.	2.26			Av.	56	--	41	33	55	25	34	56	57	43	
F-104	0.70	98.2			6	2	--	2	6	0	1	0	0	3	3	
F-104	1.36	105.0			2	17	--	3	7	0	4	0	0	9	0	
F-104	1.40	105.3			6	30	--	16	16	12	9	11	9	51	15	
F-104	1.50	106.1			4	29	--	27	10	29	23	54	43	4	22	
F-104	1.69	107.3			1	75	--	29	43	38	0	11	22	67	38	
F-104	2.00	109.0			2	33	--	31	0	7	17	75	57	0	39	
F-104	2.80	112.5			7	74	--	63	54	50	22	62	89	100	73	
F-104	3.30	114.2			2	98	--	82	63	75	78	100	79	50	100	
	Av.	1.83			Av.	45	--	32	25	26	19	39	36	36	36	
XB-70	1.36	102.0			2	21	--	28	32	15	11	19	39	74	25	
XB-70	2.06	109.3			4	53	--	25	33	32	9	6	21	68	27	
XB-70	2.52	111.4			2	65	--	33	55	53	18	10	39	67	28	
	Av.	1.88			Av.	46	--	29	40	33	13	12	33	70	27	
WC-135B	8000	1.76	85		2	1	--	1	0	0	4	0	0	9	0	
KC-135	3000	1.6	95		4	2	5	2	0	0	2	3	0	0	3	
WC-135B	4000	1.76	95		4	3	--	2	7	0	0	0	0	0	2	
WC-135B	2000	1.76	105		9	24	--	11	17	11	5	4	4	17	14	
KC-135	1000	1.5	107		4	28	33	22	6	30	21	15	16	11	38	
WC-135B	1300	1.76	110		2	41	--	14	0	0	27	5	0	44	15	
WC-135B	1000	1.76	113		3	70	--	35	25	50	22	33	15	65	44	
WC-135B	800	1.76	116		6	77	--	43	44	56	19	47	24	85	49	
KC-135	500	1.5	115		2	80	62	49	19	80	50	80	13	33	59	
WC-135B	500	1.76	119		2	92	--	61	38	71	40	53	34	81	52	
WC-135B	260	1.76	125		2	84	--	70	53	85	54	78	58	80	81	
	Av.	1.11			Av.	47	--	27	19	35	22	29	15	38	32	
Number of Persons per Mission						40-48	9-11	51-70	6-8	5-8	8-11	8-10	6-8	5-6	13-18	

*The ratings are only for the first aircraft of a pair.
 †Used in Phase I only.

Table 5

PERCENTAGE OF PERSONS WHO RATED SONIC BOOMS AND NOISES AS UNACCEPTABLE (LESS THAN JUST ACCEPTABLE) LISTENERS FROM FONTANA AND REDLANDS

Group	SOURCES OF BOOMS AND NOISES						LOCATION OF PERSONS											
	A/C	Alt.	EPR	PNDD	Number of Missions†	Nom. Peak Overpressure (psf) dBC	Out-door	In-door	E1-BR	E1-LR	E1-FK	E2-BR	E2-LR	E2-FK	E2-DR	E2-FK		
Fontana	B-58	1.69	107.3		6		53%	50%	53%	71%	31%	69%	15%	27%	66%			
	WC-135D	2800	1.76	100	2		5	1	7	0	0	0	0	0	0	0		
	WC-135D	1400	1.76	109	2		33	1	0	0	6	0	0	0	0	0		
	WC-135D	700	1.76	116	2		80	30	44	44	15	45	7	30	30			
				AV. 108			AV. 41	11	17	15	5	17	2	10	10			
Redlands	B-58	1.69	107.3		6		25	29	9	22	17	33	36	50	40			
	WC-135B	1800	1.76	103	2		31	4	0	7	0	0	19	0	4			
	WC-135B	1000	1.76	110	2		60	15	0	7	8	22	13	20	27			
	WC-135B	400	1.76	120	2		90	33	15	28	19	56	47	50	27			
				AV. 111			AV. 63	17	5	14	8	26	26	23	19			
Fontana & Redlands Combined	B-58	1.69					AV. 30	40	31	47	24	51	26	39	53			
	WC-135D						AV. 52	14	11	15	7	22	14	22	15			
	Number of Persons Per Mission - Fontana						35	63	8	8	10	9	8	5	16			
	Number of Persons Per Mission - Redlands						80	68	7	8	13	9	8	6	15			

* The ratings are only for the first aircraft of a pair.

Table 6. Equations to Fit the Linear Regression Lines in the Figures

Figure

- 4 Resultant peak ground velocity (in/s)
a. quarry blast - $13/(\text{ft}/\text{lbs}^{1/2})^{-0.91}$
b. surface mine blast = $55/(\text{ft}/\text{lbs}^{1/2})^{-1.23}$

$$\text{Peak over pressure in dB} = -12.3 \log_{10} (\text{ft}/\text{lbs}^{1/2}) + 145$$

- 4 Air blast (C-wt slow) = $-14.65 \log_{10} (\text{ft}/\text{lbs}^{1/2}) + 123 \text{ dB}$
(see Table 1)

$$\text{Peak over pressure in dB} = 0.842 (\text{C-wt slow}) + 41.8$$

$$\text{Peak house wall and floor velocity (in/s)} = 3.89 (\text{ft}/\text{lbs}^{1/2})^{-0.56}$$

from air blast

- 2 Peak house wall velocity (in/s) = $\text{antilog}_{10} [.0385(\text{C-wt slow}) - 4.15]$

- 9,11 % very annoyed from air blast

$$\begin{aligned} \% &= 2.97 (\text{C-wt slow}) - 285 \\ \% &= 9.41 (\text{C-wt slow}) - 994 \end{aligned} \quad \begin{array}{l} \text{Use whichever gives} \\ \text{higher \%} \end{array}$$

- 9,11 % very annoyed from ground vibration

$$\begin{aligned} \% &= 77.3 \log_{10} \text{ peak velocity} + 35 \\ \% &= 245 \log_{10} \text{ peak velocity} + 20 \end{aligned} \quad \begin{array}{l} \text{Use whichever gives} \\ \text{higher \%} \end{array}$$

Table 7. Impact of Different Blast Noise Criteria

One to Eight Air Blasts Per Day - During Daytime (7 AM-10 PM)

<u>Blast Noise Level</u>	<u>Percent population very annoyed inside dwellings</u>		
	<u>This Report</u>	<u>CHABA</u>	<u>Modified CHABA</u>
135 dB peak (110.7 dBC slow)	48	13-29	32-59
109 dBC slow	39	10-24	26-54
128 dB peak (102.4 dBC slow)	19	4-13	3-31
105 dBC slow	27	6-17	14-42
100 dBC slow	12	1-10	0-26
98 dBC slow	6	0-8	0-20

One to Eight Air Blasts Per Day - During Nighttime (10 PM-7 AM)

<u>Blast Noise Level</u>	<u>Percent population very annoyed inside dwellings</u>	
	<u>CHABA</u>	<u>Modified CHABA</u>
135 dB peak (110.7 dBC slow)	32-60	63-93
109 dBC slow	28-60	57-85
128 dB peak (102.4 dBC slow)	14-32	34-62
105 dBC slow	20-45	45-73
100 dBC slow	12-28	29-57
98 dBC slow	9-23	23-51

Table 8. Impact of Different Blast Vibration Criteria

Resultant peak ground velocity in/sec	Percent population very annoyed inside dwellings
2	94
1.75	78
1.5	64
1.25	44
1	35
.75	26
.5	12
.4	4

CHABA Residential Daytime Limit:

$$\text{Peak velocity (in/sec)} = 0.11/N^{1/2}$$

where N = number of blasts per day

CHABA Residential Nighttime Limit:

$$\text{Peak velocity (in/sec)} = 0.011$$

Fig. 1. Dwelling Wall Peak Velocity Measured vs Blast Noise
Peak Overpressure

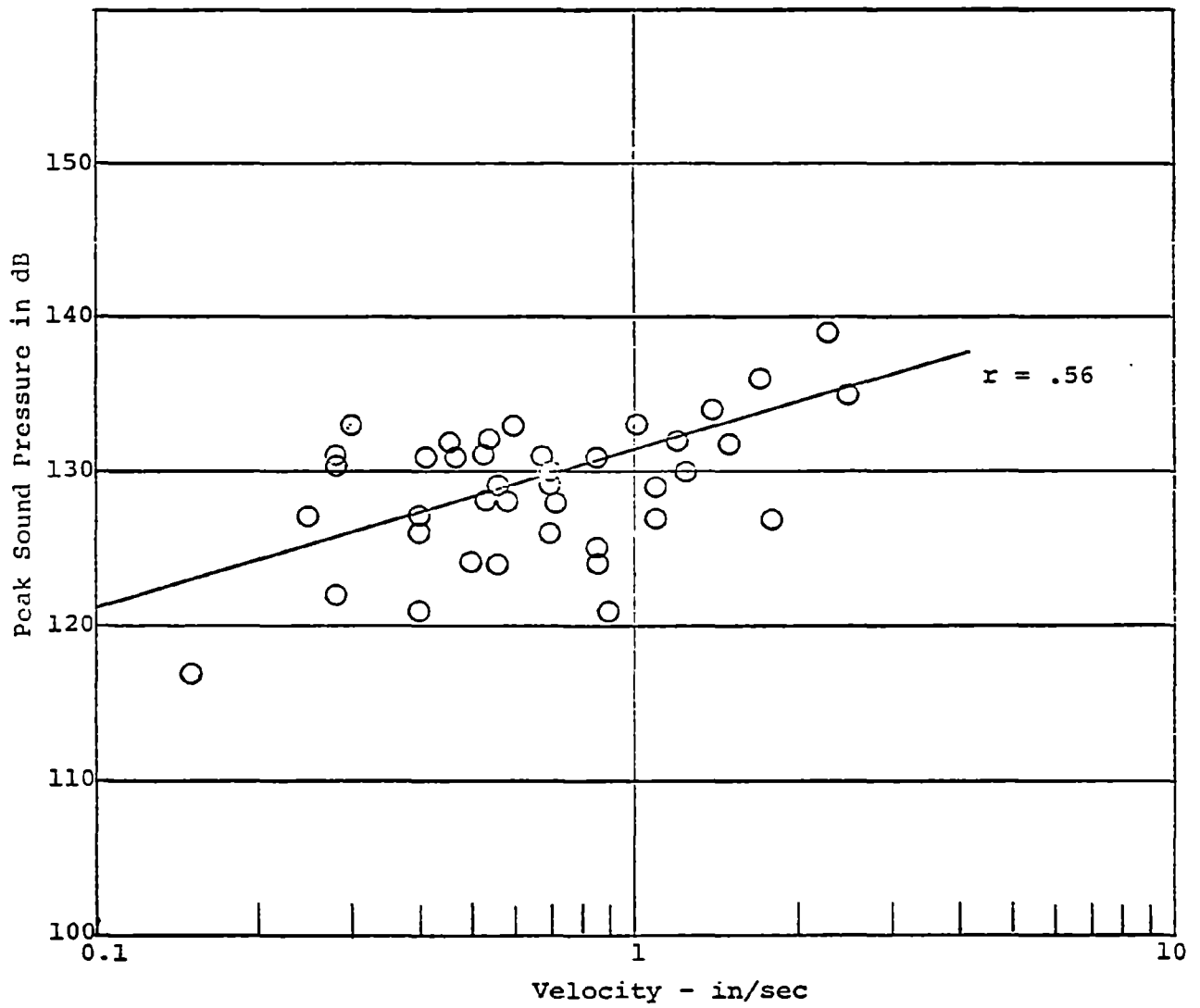


Fig. 2. Dwelling Wall Peak Velocity Measured vs Blast Noise
C-wt Slow (dBC)

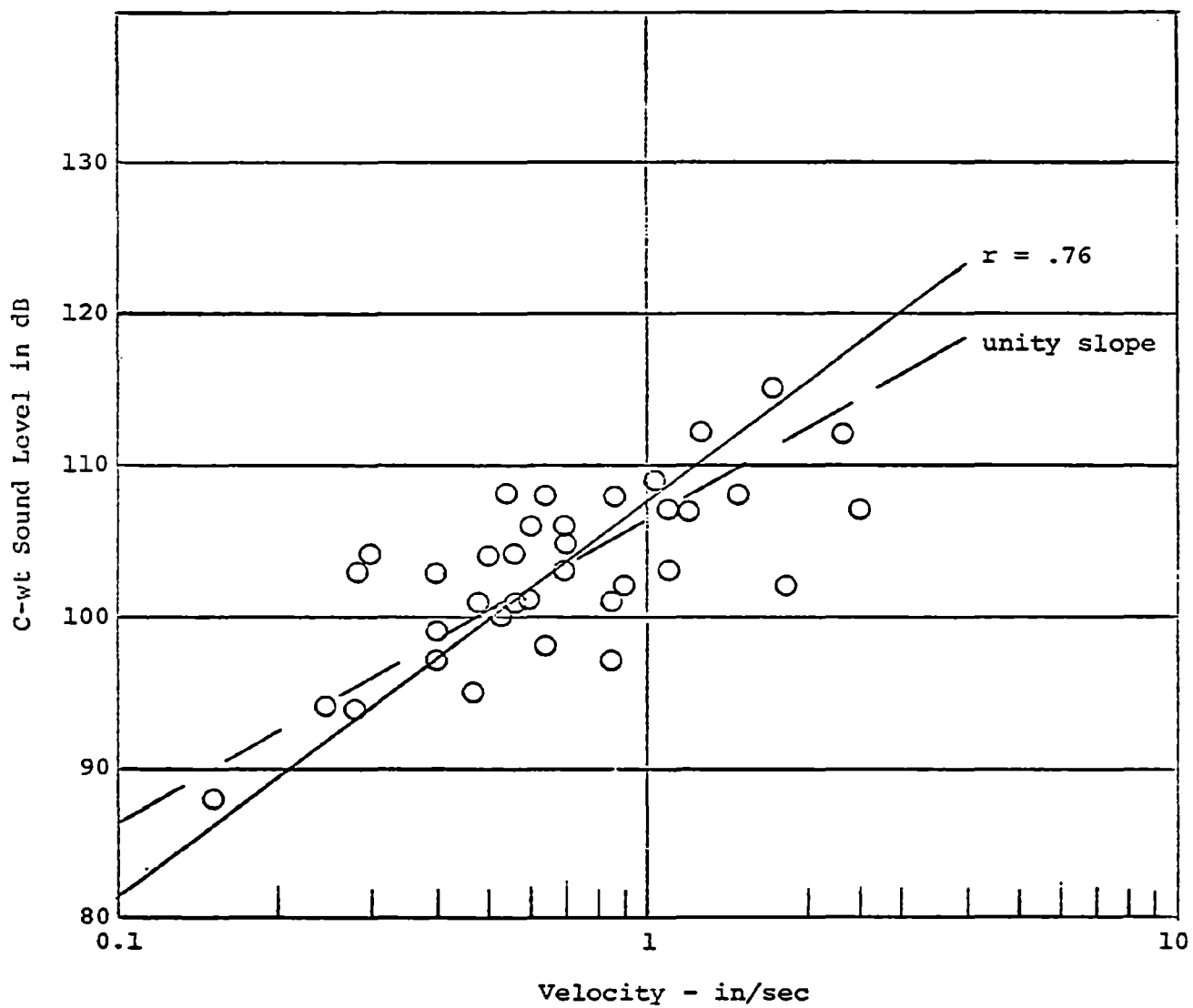


Fig. 3. Measured Difference Between Peak Sound Pressure Level
vs C-wt Slow (dBC) Sound Level for Sonic Booms and Blasting

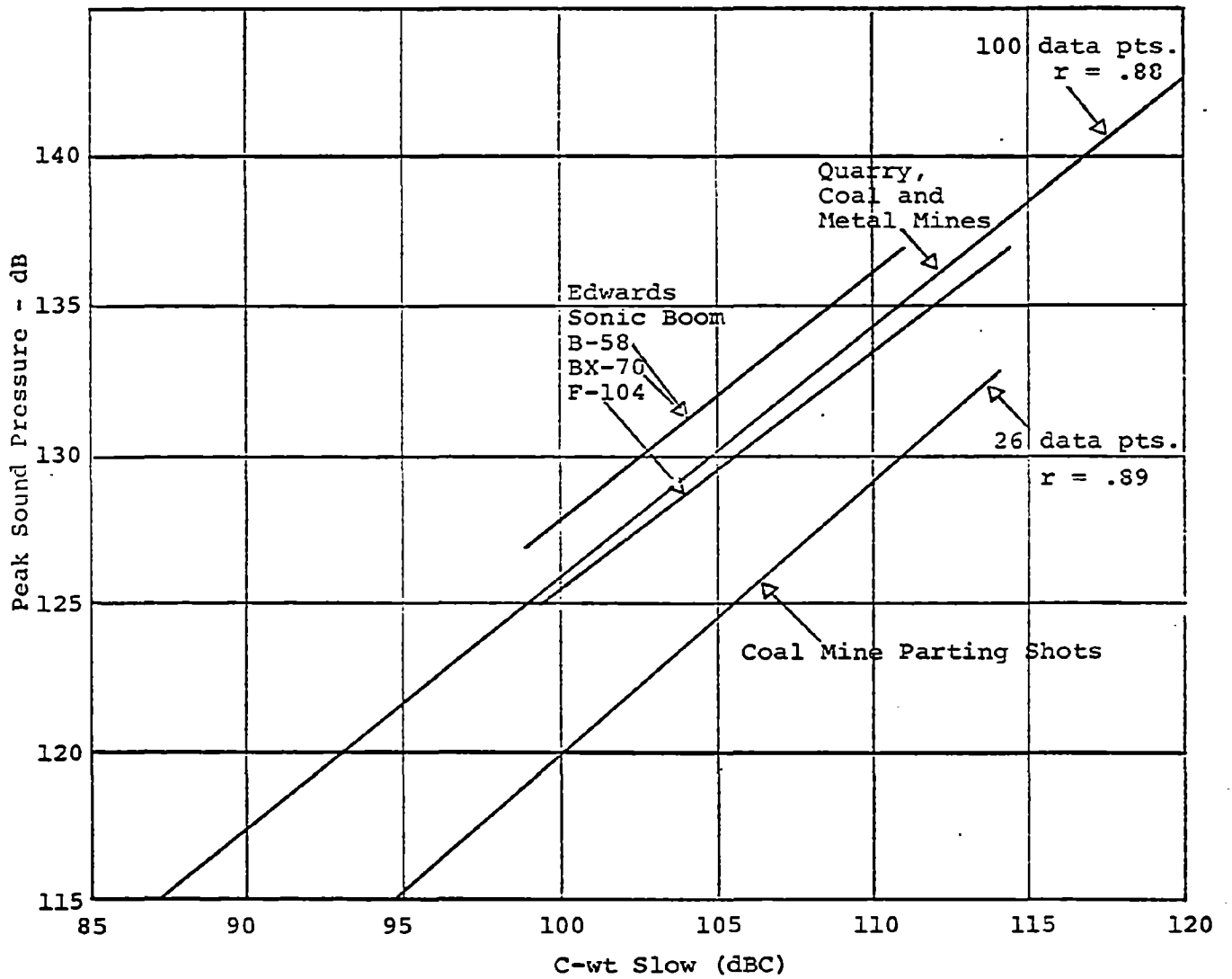


Fig. 4. Resultant Peak Ground and Dwelling Velocity
 Measured Median Values vs Scaled Distance

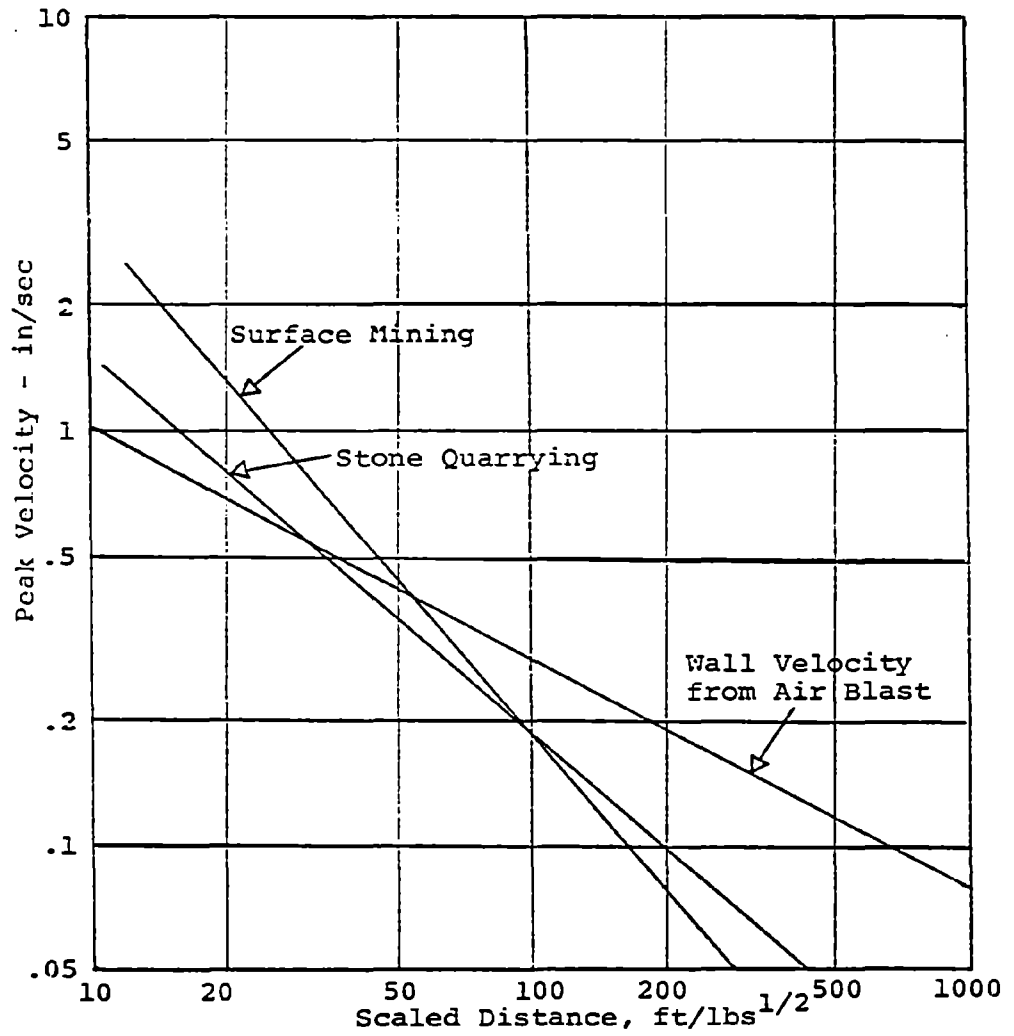


Fig. 5. Air Blast vs Scaled Distance Measured Under Different Wind Conditions at Quarries

- △ Down-wind in front of face
- Cross-wind or up-wind in front of face or down-wind behind face
- Cross-wind or up-wind behind face

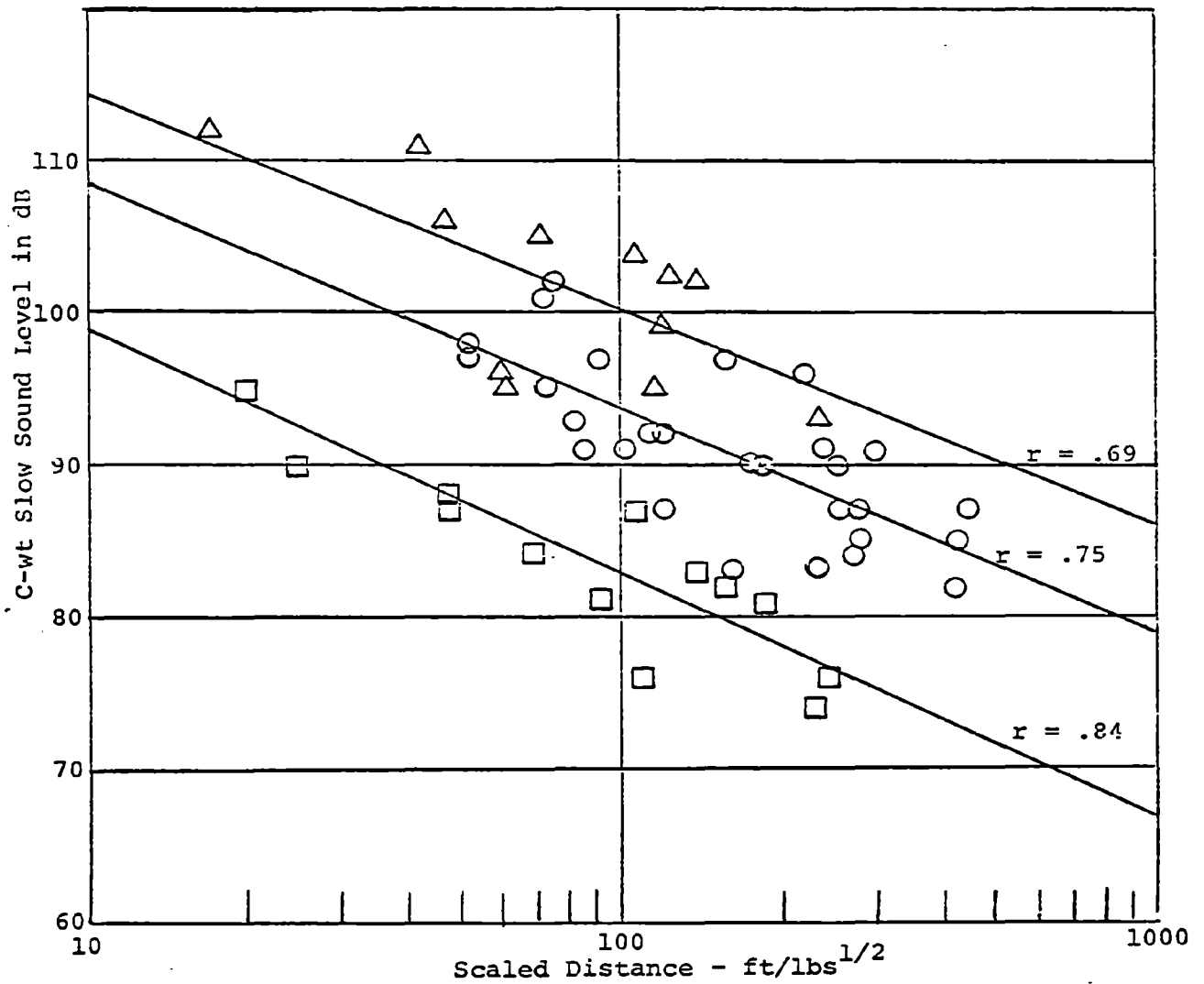


Fig. 6. Noise from Parting Shots in Open Pit Mines
C-wt Slow vs Scaled Distance

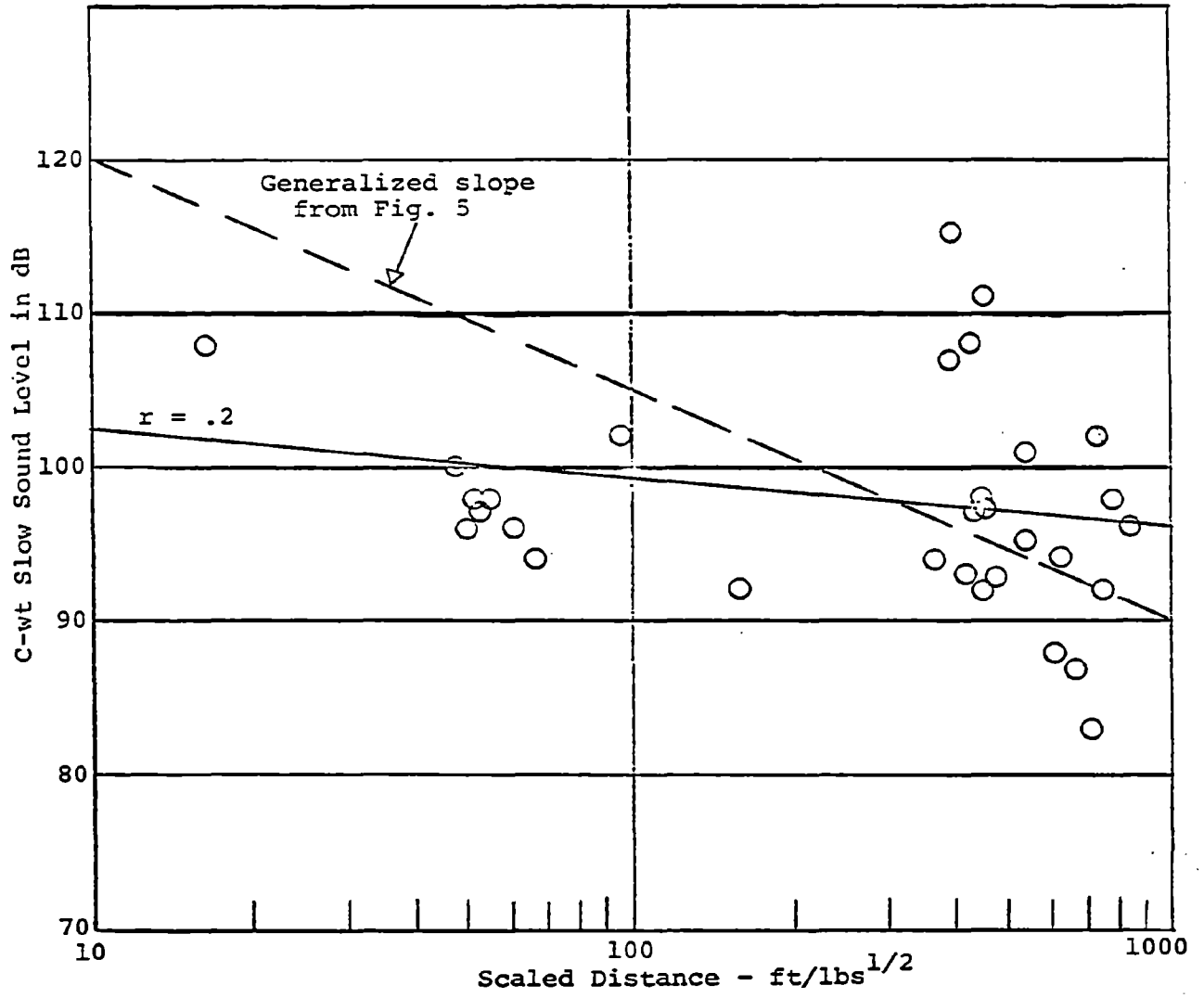


Fig. 7. Estimated Dwelling Wall Velocity vs Scaled Distance
Due to Blast Noise. See Table 1.

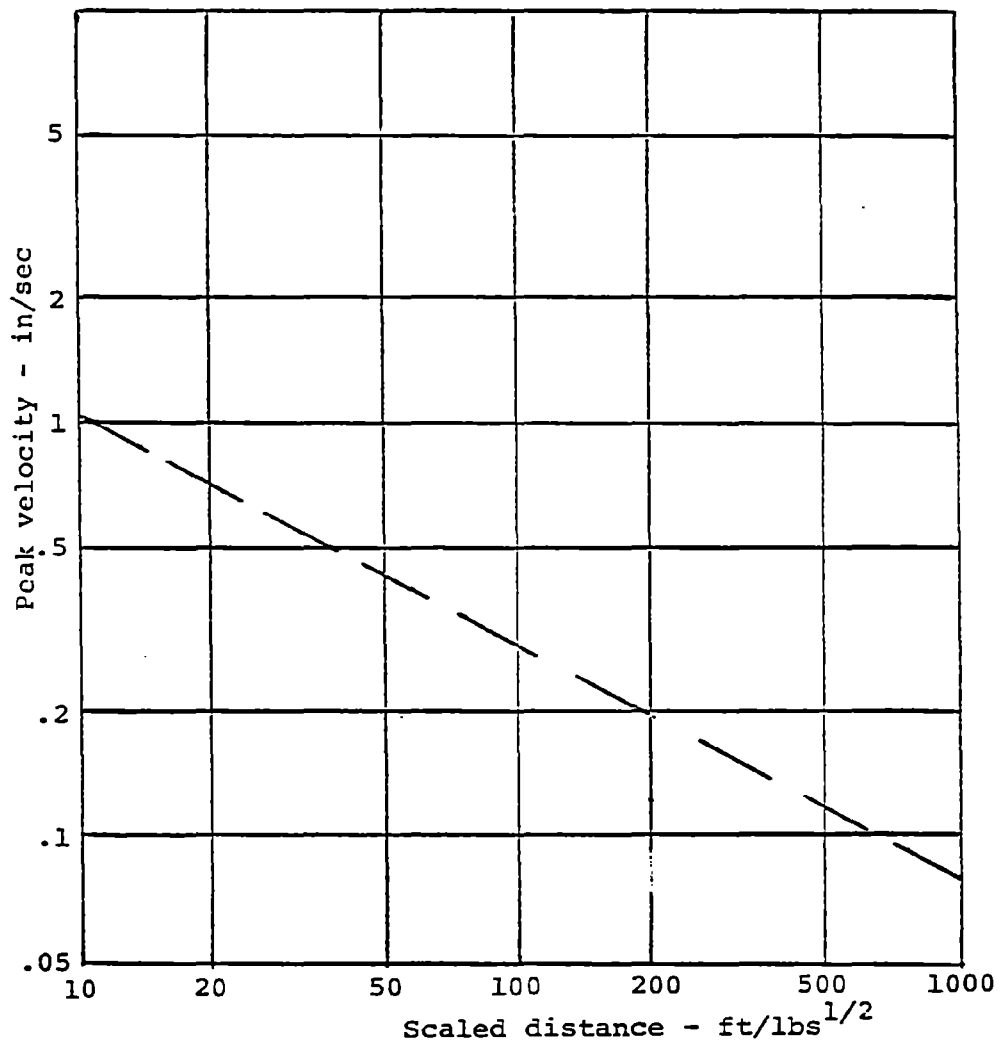


Fig. 8. Oklahoma City Sonic Boom Study
Percent Very Annoyed by House Rattles vs Outdoor
Sound Level, C-wt Slow

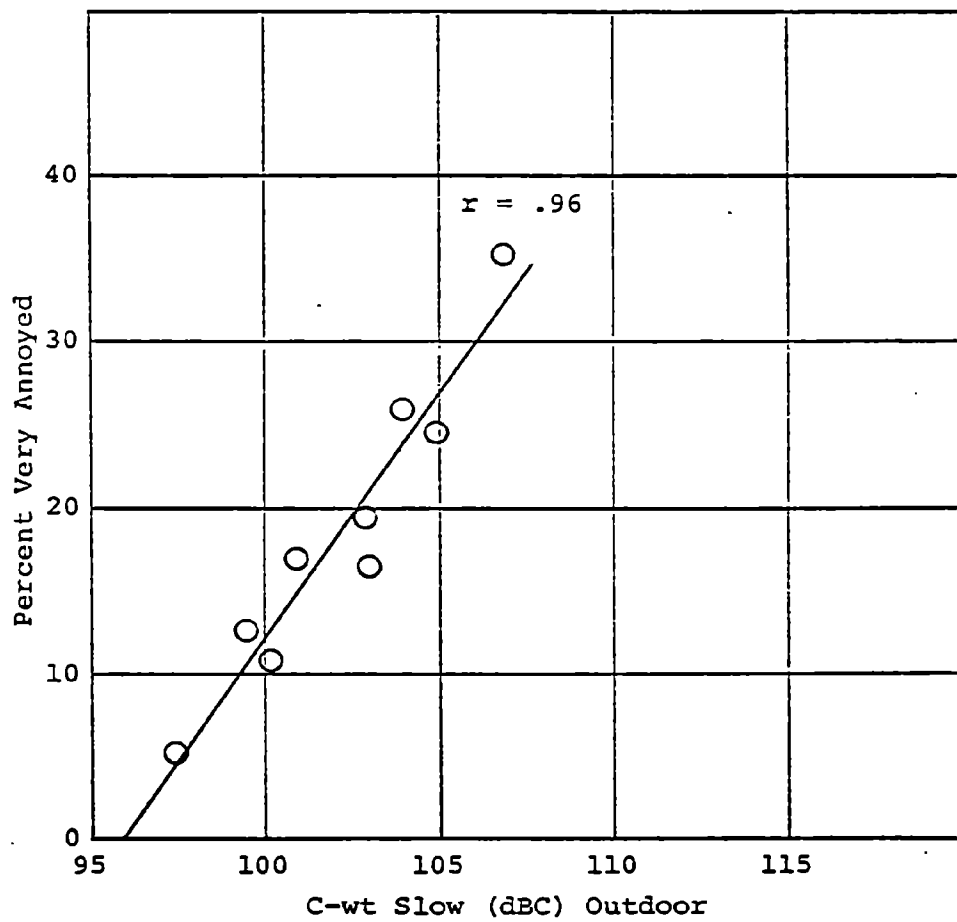


Fig. 9. Percent of Residents Estimated to be Very Annoyed by Air Blast or Ground Vibration, Resultant Peak Velocity, Due to Blasting

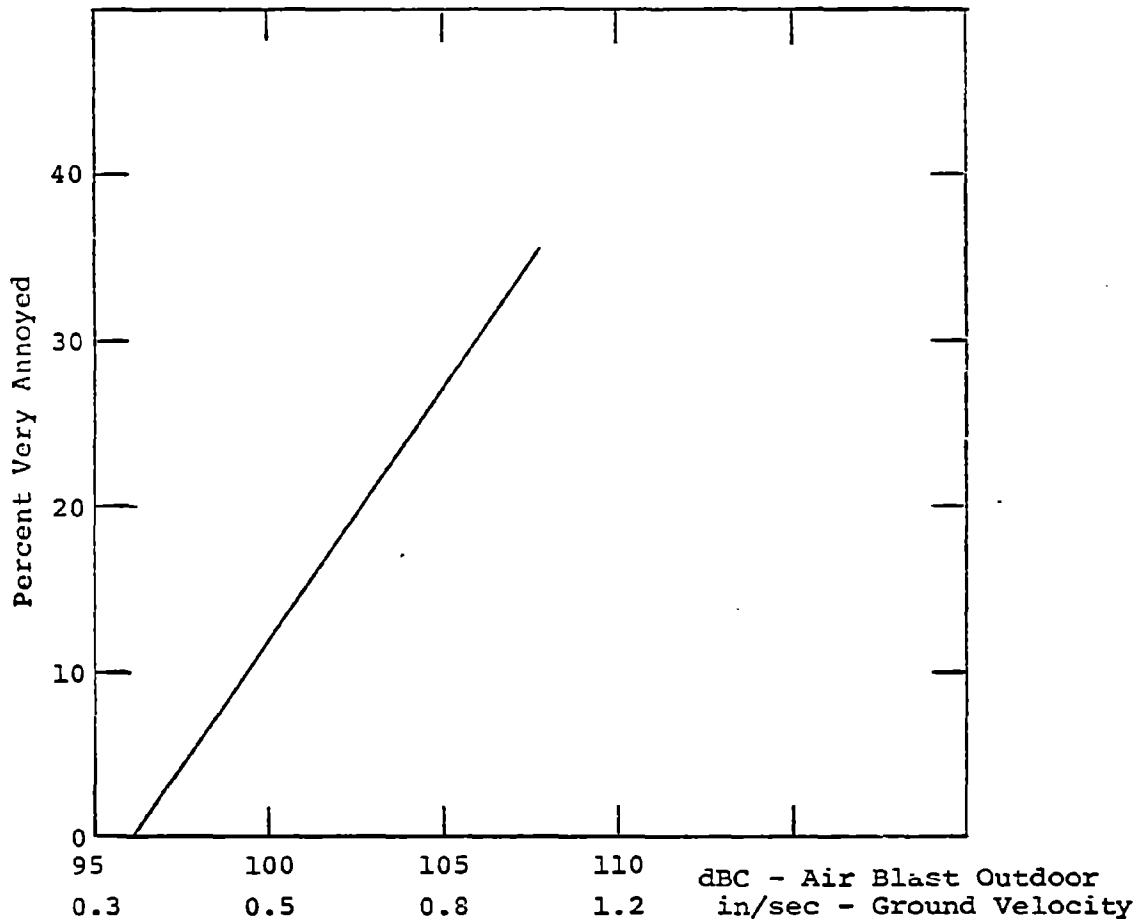


Fig. 10. Sonic Boom Tests on Edwards Air Force Base Residents. All Tests Inside and Outside of Two New Wood Frame Homes (windows and doors closed). Subjects Judged Acceptability of Sonic Booms vs Boom Intensity.

△ F-104 Subjects Outdoor	—— Indoor Regression Lines
▲ F-104 Subjects Indoor	—— Outdoor Regression Lines
○ B-58 Subjects Outdoor	----- Oklahoma City Boom Data
● B-58 Subjects Indoor	F Fontana Subjects Indoor
□ XB-70 Subjects Outdoor	R Redlands Subjects Indoor
■ SB-70 Subjects Indoor	

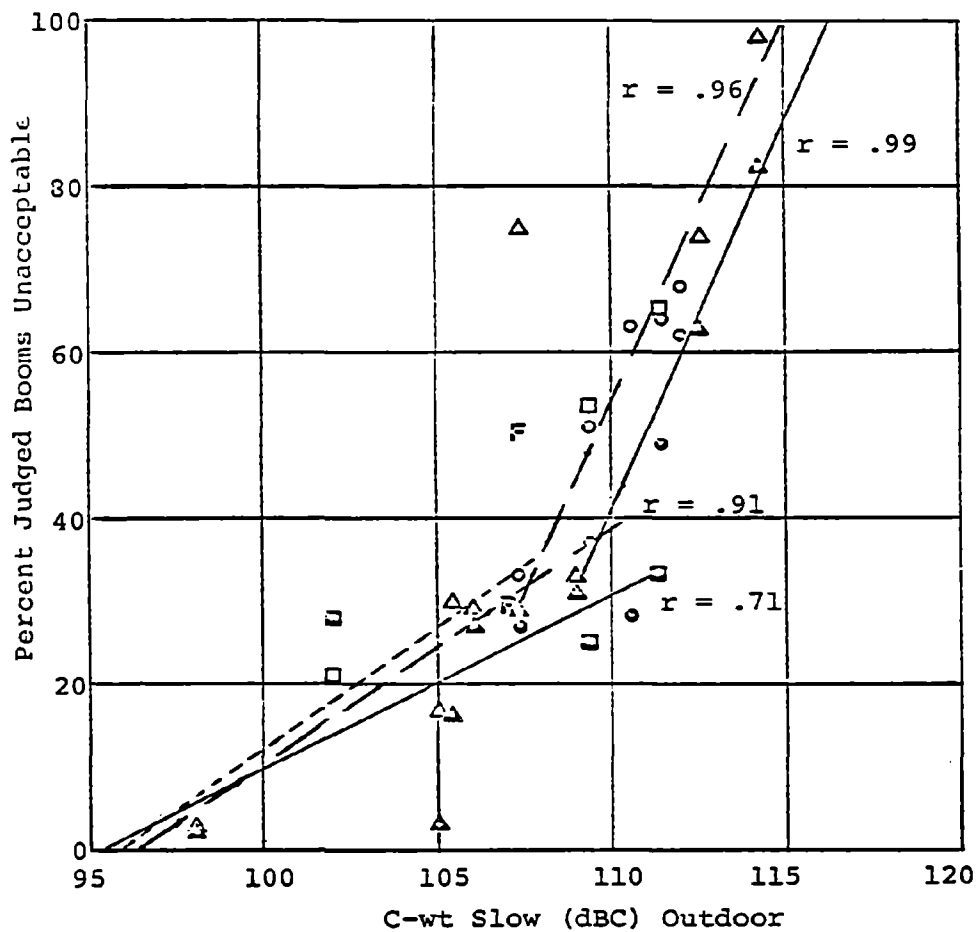


Fig. 11. Estimate of Percent of Residents Very Annoyed by Air Wave from Blasting. Outdoor Blast Noise Exposure to Dwellings.

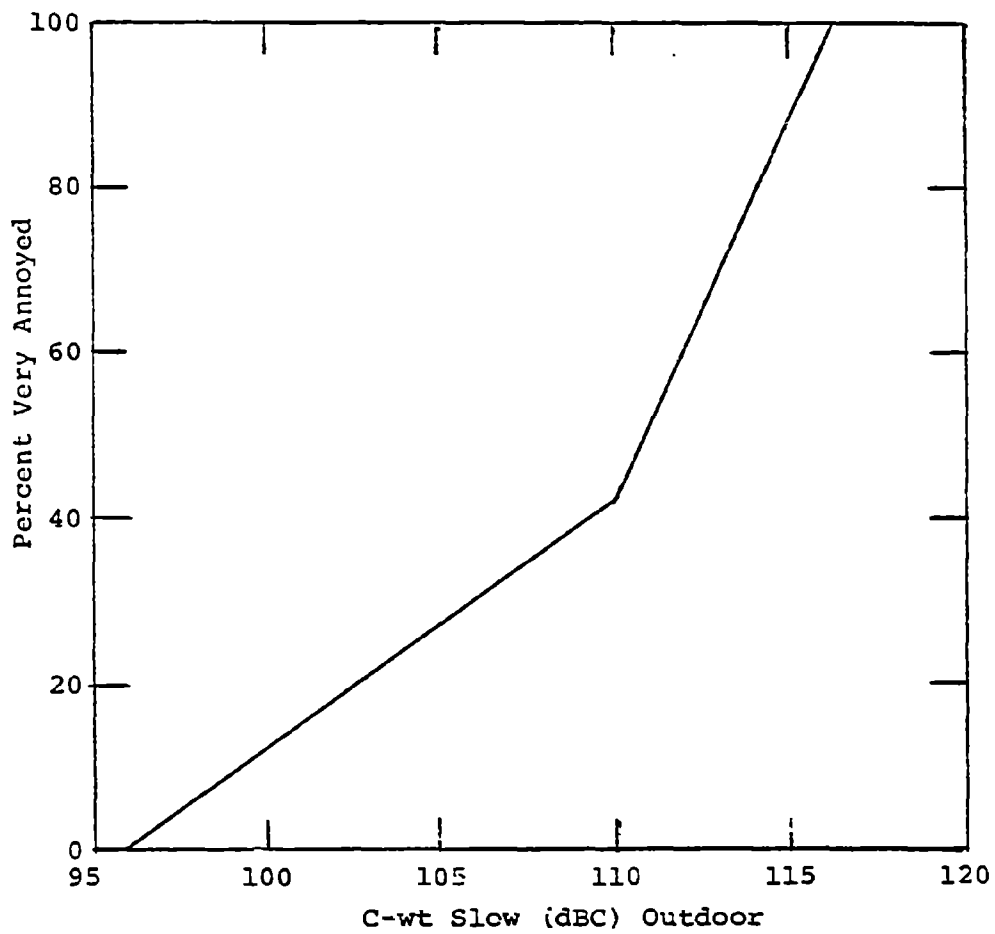
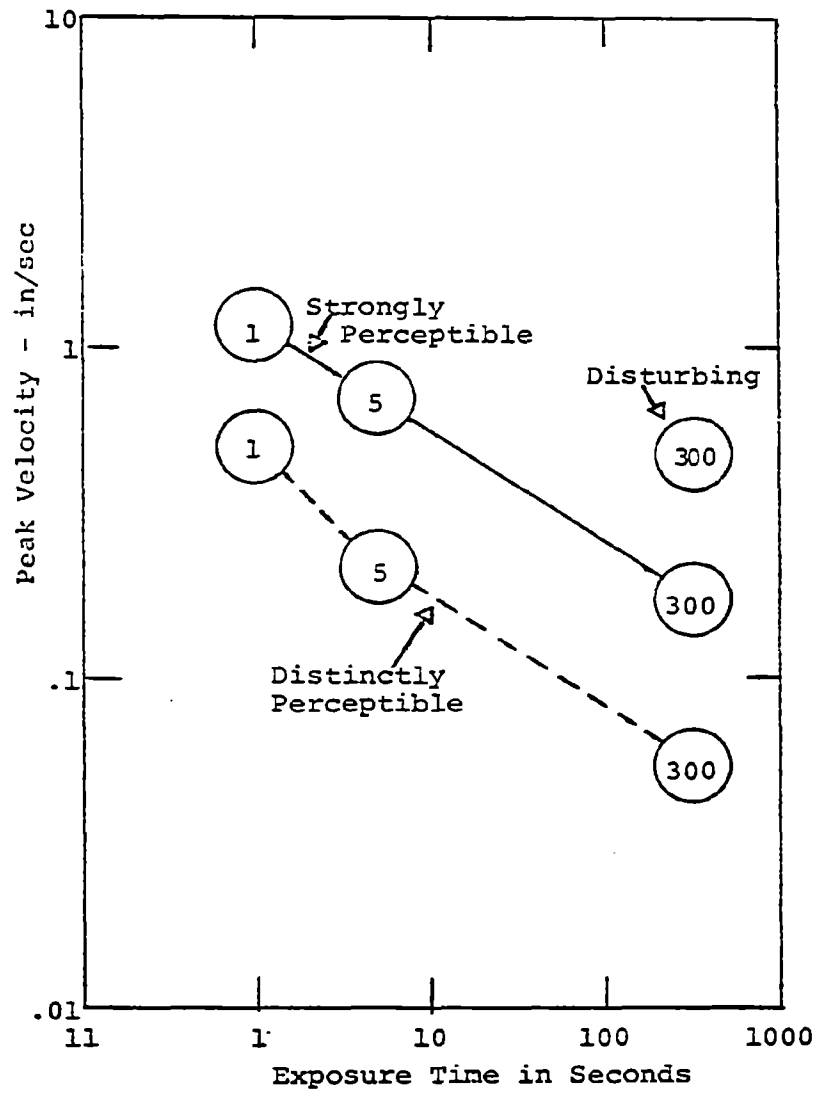


Fig. 12. Human Perception to Vibration vs Exposure Time at 10 Hz



FOOTNOTES

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SECTION TWO

TECHNICAL AND COST ISSUES

-271a-

PART ONE

COST MODEL FOR
SURFACE COAL MINE BLASTING

I. INTRODUCTION

On-site investigations were conducted at forty-three coal strip mines during 1978 and 1979.* The purpose of these site visits was to collect technical and economic data on drilling and blasting. Relevant information was obtained from forty-two of the mining companies participating in the study located in nine major mining regions within eight states** east of the Mississippi River.

Phase I concluded in 1978 by summarizing the current state-of-art in blasting techniques and modifications of the techniques in order that blast designs comply with the regulations set forth by the Surface Mining Control and Reclamation Act of 1977. Additionally, drilling and blasting costs were evaluated for various mining methods and regions within the Mid-West and Appalachia.

Phase II further explored blast design modifications and assessed the economic impact of restricting blast designs (more specifically, explosive charge weight per delay) to comply with four levels of ground motion generated from blasting (2.0, 1.0, 0.5 and 0.25 inches per second). Field investigations during Phase II (1979) concentrated on defining the operational functions of drilling and blasting with unit costs for the following components of the function: products, labor and equipment. By averaging detailed information on production and operations for sites visited during 1978, costs of three representative methods of mining were analyzed by hypothetically restricting ground motions generated to 2.0, 1.0, 0.5 and 0.25 inches per second (resultant velocity) at the nearest structure. Typical blast designs were modified to comply with the four levels of motion and the economic impact of the modifications were evaluated to develop a cost model for contour stripping, area stripping and combined contour strip/area strip mining methods. The cost models were then applied to three mine permits representative of the mining method, terrain, and demographic conditions surrounding the permits observed over the time period of study.*** Cost calculations were performed to evaluate drilling and blasting costs over the live of the permits in compliance with the four levels of ground motion.

Table 1 summarizes the total number of mining companies visited over the 1978-1979 period of investigation. The total annual coal tonnages for all companies within the eight states are shown. Included is the percentage of total surface coal mined in each state or region for 1977 as represented in this study. Thus, 40% of the 1977 surface coal production in Indiana was produced by the five companies investigated and included in this study. This assumes production figures have essentially remained constant over a three year time period. The

* See Appendix A

** The eight states include: Pennsylvania, West Virginia, Ohio, Illinois, Indiana, Kentucky, Alabama and Virginia.

*** See Figures 10 - 15. See also Appendix A

validity of this argument is reflected in observations made in the field. Any increase in coal production from 1977 tended to be repressed in 1978 by the coal strike during the early months of that year and in 1979, due to a poor coal market.

Table 2 shows the breakdown of production for the forty-two mines included in the analysis. The forty-two companies are categorized by mining method as compared to 1977 surface production figures summed for those states characteristically using similar methods of mining. A regional classification of mining methodology has been recognized by Skelly and Loy in a recent study entitled "Economic Engineering Analysis of U.S. Surface Coal Mines and Effective Land Reclamation" (Ref. 5). Each region typifying a mining method, based on geological and topographical conditions, encompasses specific states. These states are defined in Footnote (1) of Table 2 as defined regionally in Reference 5.

Of the 416,945,000 net tons mined in 1977 by surface methods, 61.3% was produced in the eight regions investigated. Furthermore, these regions represent 96.6% of the surface production east of the Mississippi River. The forty-two companies included in the study produced a total annual tonnage of 41,299,000 which is 16.2% of the total annual tonnage extracted in 1977 within the eight regions.

Table 1. Summary of Total Annual Coal Production Figures For All Companies Within States and Regions Investigated During 1978 and 1979.

STATE	TOTAL NUMBER OF MINING COMPANIES	TOTAL COMPANY COAL PRODUCTION ⁽¹⁾	PERCENTAGE OF 1977 SURFACE PRODUCTION (STATE OR REGION) REPRESENTED IN STUDY ⁽²⁾
Alabama	10	3412	23.3
Illinois	3	9200	38.0
Indiana	5	10,980	40.0
Kentucky Eastern	3	2394	4.7
Western	1	600	2.2
Ohio	4	2058	6.4
Pennsylvania	4	6359	4.2
Virginia	3	1320	11.3
West Virginia	10	6416	30.0
TOTAL	43	42,739	

(1) Production figures in thousands of net tons.

(2) 1977 surface coal production figures from Keystone Coal Industry Manual, 1978.

Table 2. Summary of Total Annual Coal Production For All Companies Categorized by Mining Method and the Percentage of 1977 Surface Coal Production Represented in the Study by Mining Method.

	(2)	(3)	(4)	(5)
MINING METHOD	NUMBER OF COMPANIES	TOTAL ANNUAL COAL PRODUCTION . ALL COMPANIES (Thousands of Tons)	TOTAL 1977 PRODUCTION FOR REPRESENTATIVE STATES (1)	PERCENTAGE OF 1977 PRODUCTION REPRESENTED IN STUDY
CONTOUR STRIP (Type (1))	14	7859	84,170	9.3
AREA STRIP (Type (2))	16	30,098	79,545	38.0
CONTOUR STRIP/ AREA STRIP (Type (3))	12	3342	91,780	3.6
TOTAL	42	41,299	255,495	

(1) Representative states are as follows: (Contour Strip) Eastern Kentucky, West Virginia, Virginia; (Area Strip) Illinois, Indiana, Western Kentucky; (Contour Strip/Area Strip) Ohio, Pennsylvania, Alabama; 1977 surface coal production figures from Keystone Coal Industry Manual, 1978.

(2) Percentages in Column 5 are Column 3 divided by Column 4.

II. SUMMARY OF MINES

Three general methods of mining were defined for this study. Each of the forty-two mines investigated during 1978 and 1979 were categorized by method based on regional location, site and local terrain, geology (waste material and number and quality of coal seams), as well as type and bucket capacity of major wasterock removal equipment used for primary stripping. Once the various companies were categorized, information on production, blasting techniques and unit costs were averaged to develop three representative models.

1. Mining Methods

(1) Contour Strip (Type 1)

Contour stripping methods include mines in Eastern Kentucky, West Virginia and Virginia (a typical permit with surrounding homes is shown in Figure 10). Mining progresses parallel to the contour, and mountain top removal methods are often incorporated into the design; however, no such distinction is made for this study. Slopes range from 15 degrees to 28 degrees. Multiple seams (2 to 4) are mined for high quality steam or border-blend and metallurgical grade coal. Powder factors (pounds of explosives, or ANFO, per cubic yard of wasterock broken) range from 0.5 to 3.0, with the higher ranges observed in parting layer blast design. Front-end loaders with 10 to 15 cubic yard bucket capacities remove fragmented rock.

(2) Area Strip (Type 2)

Area strip mining methods include sites in the flat terrain of Illinois, Indiana, and parts of Western Pennsylvania and Northern Alabama. (A typical permit with surrounding homes is shown in Figure 12.) Large draglines or shovels, with bucket capacities generally in excess of 40 to 60 cubic yards, expose one to two seams of steam grade coal. Wasterock geology is comprised of less competent, more weathered bedrock than observed in contour strips and powder factors range from 0.3 to 1.6 lbs./cubic yard.

(3) Contour Strip/Area Strip (Type 3)

Rolling hill terrain describes the variable topography in Western Pennsylvania, Eastern Ohio, and parts of Alabama and Northern West Virginia. (A typical permit with surrounding homes is shown in Figure 14.) Broad, flat valleys are flanked by moderately steep slopes ranging from 10 to 15 degrees. To accommodate the variation in surface topography, both small draglines (with bucket capacities generally 7 to 30 cubic yards) and front-end loaders work the lower parts.

During the course of the investigation, mining methods typical to the terrain condition represented in Type 3 were moving away from

traditional contour stripping designs toward area stripping methods. This was observed to be most prevalent in Western Pennsylvania and Alabama. The high cost of utilizing small capacity draglines and front-end loaders coupled with the increasing costs of reclaiming the highwall remaining after contour strip mining has forced a change in methods. Larger draglines are being placed on greater acreage, mining with higher ratios of stripping, and progressing across variable terrain in area strip fashion. As a result of this change, area strip methods in Table 2 show an extreme proportion (38%) within this category, and include not only those operations in the flat terrain regions of the Mid-West, but also regions in Upper and Lower Appalachia.

2. Summary of Production and Blast Designs for Mining Method Scenarios

Tables 3 and 4 summarize production and blast designs for the three methods of mining. The figures presented are the results of averaging technical, production and economic data obtained from the 14, 16, and 12 mine sites using contour stripping, area stripping, and contour strip/area strip mining methods respectively.

(1) Production

An average stripping ratio for each method was obtained by calculating the sum of all companies average production and stripping ratios, and applying the following formula:

$$\frac{\sum_{i=1}^n [(P_i) (SR_i)]}{\sum_{i=1}^n (P_i)}$$

where, P_i = the average production, by site, for all sites owned and operated by the company
 SR_i = the average company stripping ratio for all job sites

Once averages were obtained for the number of coal seams and a rate of annual coal production, the remaining production figures in Table 3 were computed. These were checked against the figures from each mine within the category to ensure the average conditions reflected a realistic scenario. For all cases, the volume of wasterock fragmented represents an average of 92.5% of the total waste handled, as typically a portion of the surface unconsolidated material is removed before blastholes are drilled.

Table 3. Summary of Operations for Three Scenarios of Mining Methods Developed for Cost Analysis. All figures for Coal Tonnage and Waste Yardages are Averaged from Forty-Two Mining Companies Investigated.

		COMPOUR STRIP	AREA STRIP	COMPOUR STRIP/ AREA STRIP	
Number of Job Sites per Company		3.6	1.0	2.3	
Silo Stripping Ratio (Company Average)		14.5	16.0	17.3	
Number of Coal Sumps per Silo		2.5	1.0	1.7	
ANNUAL	Coal Production (Tons)	320,000	1,000,000	140,000	
	Wastorock Fragmented (Cubic Yards)	4,273,360	14,092,124	2,244,520	
WEEKLY	Coal Production (Tons)	Total	19,231	2692	
		1	10,909	1574	
		2	8242	1110	
	Coal Sump Thickness (Feet)	1	4.16	2.83	2.70
		2	4.16	2.16	1.92
		3	2.08	-	-
	Sump Production Area (Square Foot)	1	14,796	97,076	14,557
		2	14,796	95,394	14,557
		3	14,784	-	-
	Volume of Wastorock Fragmented (Cubic Yards)	OB	32,080	215,725	26,909
PAIT		24,660	70,662	16,175	
PAIT'		24,610	-	-	

Table 4. Summary of Blast Designs (Unrestricted Case) For Three Scenarios of Mining Method Developed For Cost Analysis as Averaged From Forty-Two Mining Companies Investigated.

		CONTOUR STRIP	AREA STRIP	CONTOUR STRIP/ AREA STRIP
OVERBURDEN	Borehole Diameter (Inches)	7-4	9-4	7-4
	Powder Factor (Lb./ANFO/CY)	1.45	0.45	0.90
	Charge Weight/Delay (Lb./ANFO)	630	810	450
	Burden x Spacing x Depth (Ft.)	13 x 15 x 60	27 x 30 x 60	17 x 17 x 50
	Cubic Yards per Hole	433	1800	535
	Cubic Yards per Shot	17,333	51,000	26,759
	Total Number of Holes	40	30	50
	Holes by Holes in Row	5 x 8	5 x 6	5 x 10
	Approximate Shot Size (Ft. ²)	7800	24,300	14,450
	Number of Shots per Block	2	4	1
	Borehole Diameter (Inches)	7-4	5	7-4
	Powder Factor (Lb./ANFO/CY)	2.00	0.80	1.20
PARTING	Charge Weight/Delay (Lb./ANFO)	100	85	225
	Burden x Spacing x Depth (Ft.)	12 x 12 x 45	11.5 x 13 x 20	12 x 14 x 30
	Cubic Yards per Hole	240	111	187
	Cubic Yards per Shot	6180	14,396	5610
	Total Number of Holes	27	130	30
	Holes by Holes in Row	3 x 9	13 x 10	3 x 10
	Approximate Shot Size (Ft. ²)	3800	19,435	5040
	Number of Shots per Block	4	5	3

(2) Blast Design and Geology

The typical blast designs presented in Table 4 were developed from averaging designs and geological conditions for all forty-two mine sites within respective categories. Designs were averaged in two stages; first burdens and spacings were calculated without regard to total hole depths but rather in relation to blasthole diameter and powder factor used in design. Powder factors were thought to be indicative of general geologic conditions. Secondly, geologies for the various mine sites within each category were carefully examined, matched with powder factors, and average overburden and parting layers depths were computed for typical geological conditions. Average rock layer depths were then matched with burdens and spacings obtained in the first step and checked with average powder factors, to compute total shot volumes while keeping production requirements constant for each mining method. Seam production areas (Table 3) were matched with a reasonable total shot size (based on observations made in the field) to determine the number of shots required per week. Additionally, the use and movement of waste removal equipment were considered and matched to the shot size. Blasthole layout design and powder factors were matched not only for drill hole diameter but for size and type of removal equipment. As a result, blast designs for the area strip scenario use lower powder factors, the depths of shots (number of rows) are sufficiently broad for dragline removal, and the sequence of hole initiation promotes in-place fragmentation and highwall movement toward the previous shot. On the other hand, the blast design for contour strip, and to some degree, the contour strip/area strip method, allows for more movement and directional throw, using higher powder factors (necessary for smaller overburden removal equipment) and narrower bench widths.

Figure 1 shows the stratigraphy for the three mining methods as averaged for forty-two mine sites. The geologies simulate four often encountered difficult blasting conditions.

- (a) Sandstone caprock layer (contour strip - overburden) - Difficulties arise when explosives are not sufficiently high within the borehole to promote proper fragmentation of the caprock.
- (b) Competent sandstone toe rock (contour strip - parting) - A high explosive charge is required at the hole base, however, the coal beneath must not be damaged or displaced.
- (c) Hard, thin parting layers of limestone or shale (area strip - parting) - High powder factors are required and explosive loading leaves insufficient room for stemming in thin layers. Commonly, wet hole conditions lubricate stem material and promote frequent blowouts during detonation.

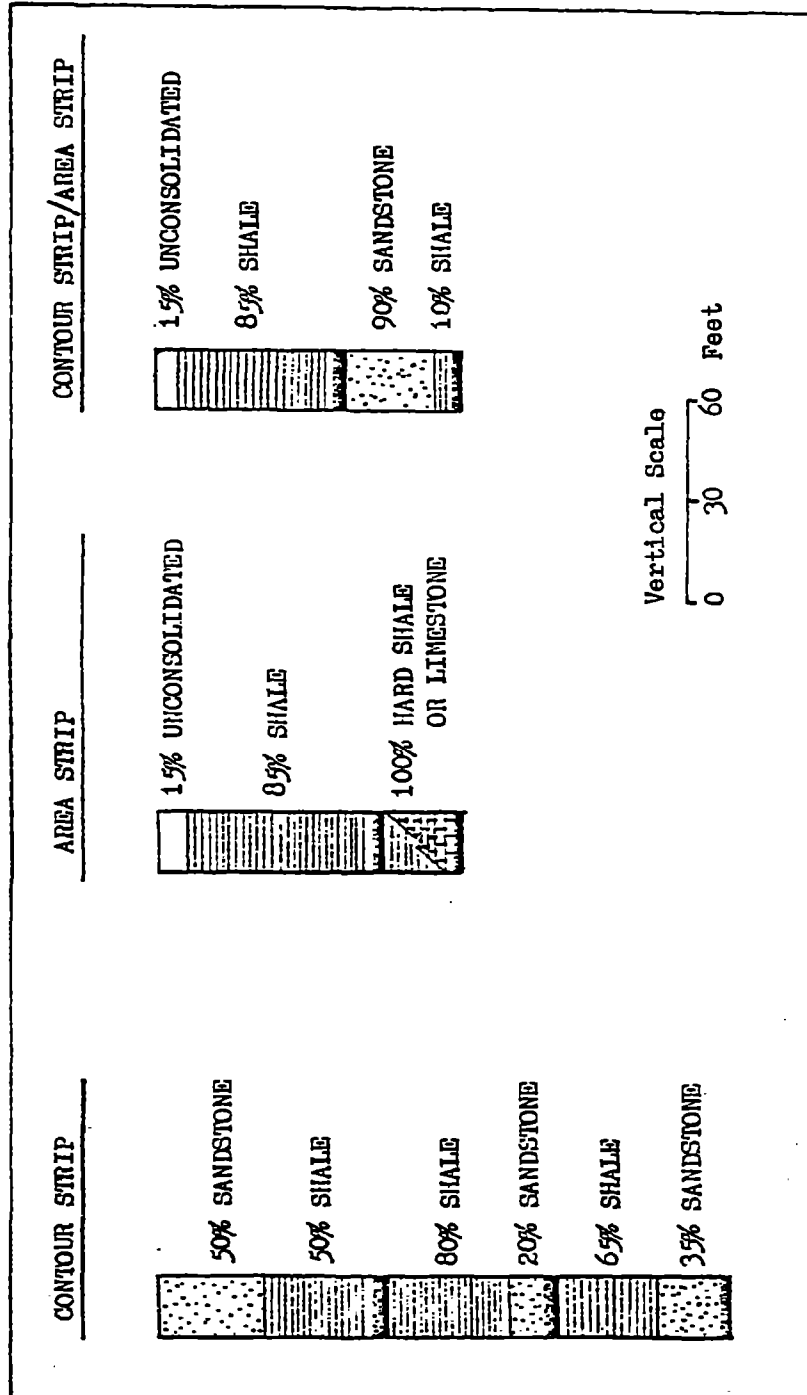


Figure 1. Typical Stratigraphic Columns For Three Scenarios of Mining Methods Showing the Average Range in Geology For Wasterock Units and Sequence of Coal Beds.

- (d) Hard, sandstone layers (contour strip/area strip - parting) - Slow drilling rates are encountered and the bedrock often contains numerous sets of joints. Ragged hole interiors make loading explosives at the desired densities difficult. Downhole cut-offs occur as sections of loaded holes are displaced in the blocky rock from previous hole fragmentation, particularly when inter-hole spacings are close.

III. COST CALCULATIONS

1. Assumptions

To insure uniformity in cost calculations and operational procedures among the three mining scenarios, basic assumptions were made and summarized in Table 5. All figures, rates and unit costs are representative of average conditions observed and obtained by those mine sites visited with sufficient and reliable data. In addition, time and motion studies for drilling and hole loading were conducted by the field researcher for verification. When records were available, drill penetration rates, drill bit life, drill availability and operating costs were checked. Blast product costs were available at most mines in addition to information on hourly wages. Blast designs are assumed to be integrated with the use of the sequential blast machine to maximize on the number of delay times available for modifications.

The labor component of blasting was difficult to define such that accurate cost impacts could be measured when blast design modifications were applied. Based on field observations, a three-man hole loading crew was capable of loading drill holes, monitoring shots, and taking inventories of supplies. Field measurements give a computed average of 7.5 hours to complete these tasks in a 9.0 hour shift. When blast modifications were severe, for example, with a large number of holes to drill and load per day, shot preparation and initiation can take longer than 7.5 hours. Calculating overtime as a cost increase factor is unrealistic as blasting regulations specify that loaded blastholes must be detonated during the day and during pre-determined time periods unique to each site. Most operators choose to complete all blasting prior to the beginning of second shift and in practice, employ the aid of additional men to shorten the total hours required to prepare the larger shot. For simplicity in calculations, a labor requirement factor of

$$\frac{3 \text{ men}}{7.5 \text{ hours}} = 0.4 \text{ men/hour}$$

was applied to hole loading time (daily) greater than 7.5 hours to compute the total number of men needed within the 7.5 hour limit.

Table 5. Basic Assumptions Regarding Production and Unit Costs for Cost Model Calculations.

<u>Mining Operations</u>		<u>Drilling Operations</u>	
5.5	days/week	90%	Drill Availability
9.0	hours/shift	20%	Drill Moving Time
3	shifts/day - Stripping	6.3 hours/shift	Actual Drilling
2-3	shifts/day - Drilling	(3604 annual hours)	Time
1	shift/day - Hole Loading	175 feet/hour	Drill Rate of
		(1103 feet per shift)	Bit Penetration
<u>UNIT COSTS - Drilling</u>			
$\text{Drill Cost} \frac{(1) (C_1 \times I_B) + C_3}{F_B} = \$0.51/\text{Foot}$			
C_3	= Cost of bit	\$1450	
I_B	= Life of bit (hours)	25	
F_B	= Footage drilled per 25-hour life (feet)	6000	
C_1	= Total drill cost/hour	\$65	
		$C_1 = C_D + C_O$	
		C_D = Ownership Cost	
		C_O = Operating Cost	
<u>UNIT COSTS - Blast Products</u>			
Primary Explosive - Ammonium Nitrate (ANFO)	bulk		\$ 0.074/pound
Primer	- 1-pound cast-type		1.50 /each
Electronic Delay			2.16 /each
Blasting Cap	- 60 Foot legwires		1.45 /each
	- 40 Foot legwires		0.008/foot
Connecting wire	- Copper		
<u>UNIT COSTS - Labor (Drilling and Blasting)</u>			
Wages + 30% Benefits			\$11/hour
<u>LABOR TIME - Hole Loading</u>			
Typical shots based on: 3-man crew loading/initiating shots in 7.5 hours. Any loading time greater than 7.5 hours/shift requires 0.4 men/hour for a maximum of 7.5 hours/shift spent.			

(1) From Chitwood and Norman, 1977.

Hole loading labor costs were then the total number of men times wages for the day. This procedure was deemed the most realistic based on observations made during site visits.

2. Procedure

The scaled distance formula was used to compute the necessary changes in blast designs to comply with the four levels of ground motion used in this model. In order to simplify calculations defining costs for designs modified from the typical (or normal) conditions present in Table 4, the formula used was of the following form:

$$D = SD\sqrt{W}$$

where, D is the distance in feet to the nearest dwelling or structure specified in the federal blasting laws; W is the maximum charge weight of explosives per delay detonated within any 8 millisecond time period; SD is the scaled distance factor.

Figure 2 (after Lucole and Dowding 1979) was used to compute the various values of SD corresponding to the four levels of ground motion (resultant velocity) used in the cost model. Values for the scaled distance factor were taken from the 95 percentile line, assuming that these values are a conservative estimation or, a "worst case" condition. The data shown in Figure 2 were obtained from 426 blasts in Illinois surface coal mines and represent a random sampling of blast technology, both with and without the use of control. The 95 percentile represents a penalty for poor control and thus a maximum cost to blast under highly restrictive conditions (presumming that all costs to control ground motions are the costs of blast products and labor). However, if blasts are monitored with the use of seismographs, it is possible that the 50 percentile line would represent the appropriate scaled distance values with such control and are associated with lowered blasting costs. Hence, the difference in pound per delay restrictions between the 95 and 50 percentile lines result in cost differences with the use of instrumentation.

* The scaled distance formula is defined in the Rules and Regulations of PL 95-87, Section 715.19 (Reference 2).

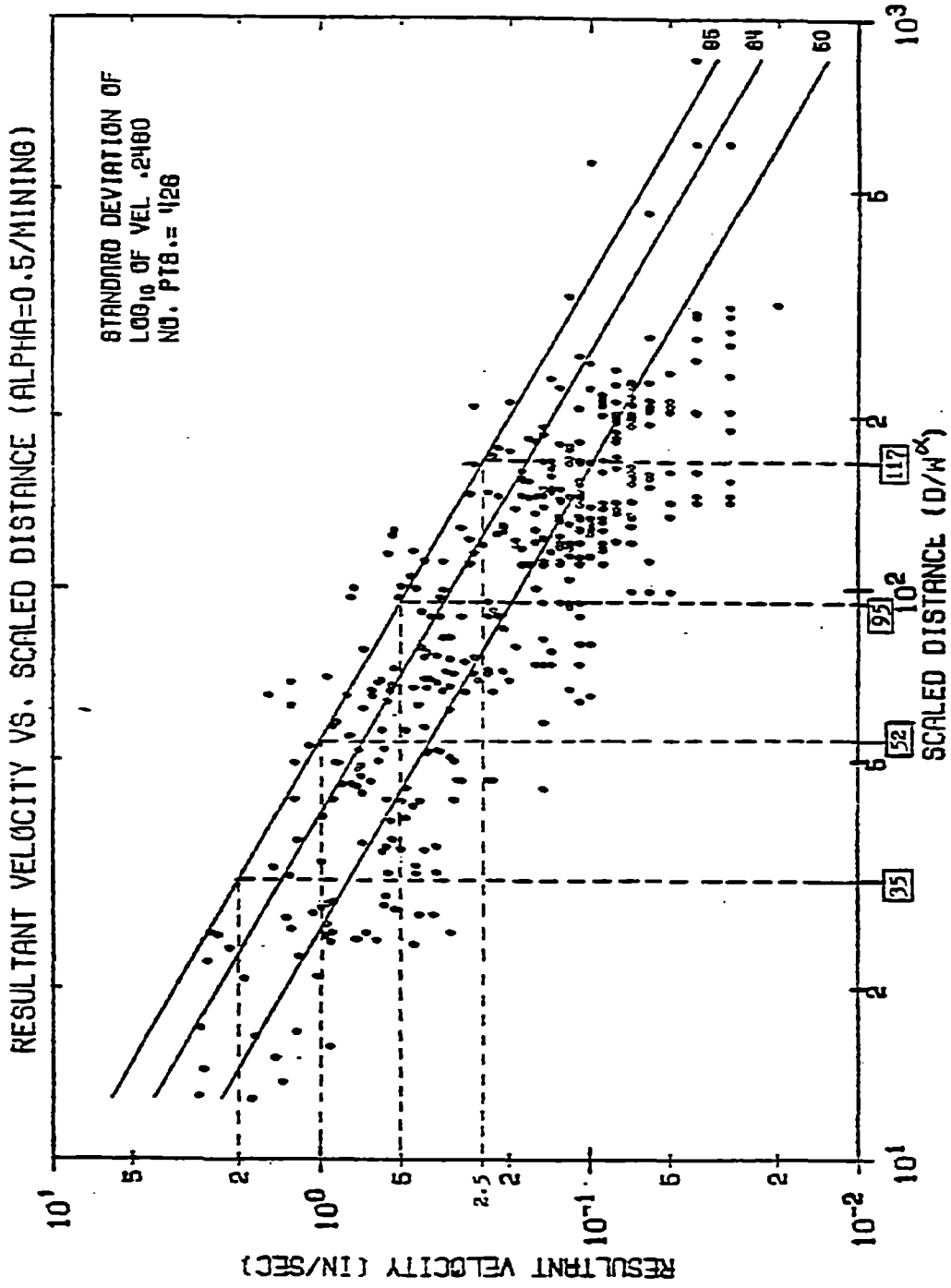


Figure 2. Resultant Velocity Versus Scaled Distance For 426 Data Points Obtained From Blasts Within Surface Coal Mines in Illinois (After Lucule and Dowding, 1979).

The values of scaled distance obtained by using the 95 percentile line in Figure 2 for resultant velocity of 0.5 and 0.25 inches per second correspond to 95 and 117 respectively. However, for blasting at 2.0 inches per second, the scaled distance used was 50, the value suggested by blasting standards prior to the 1977 Regulations. A SD value of 60 was used for blasting at 1.0 inches per second, as specified by the Regulations.

For each blast design shown in Table 4, a maximum distance of observance (D_{max}) was calculated for charge weights in design for the four levels of ground motion. Drilling and blasting costs were calculated for this unrestricted case. Values for charge weights, W, in all six designs (Table 4) were selected to compute distance values less than D_{max} to $D = 300$ feet, the minimum distance allowed by law from a blast site to a nearby structure.

For successive values of charge weight per delay (decreasing), a blast design was developed and a corresponding cost calculated, as shown in Appendix A. Total fragmentation costs per cubic yard were computed on a weekly basis and broken down by drilling (drill cost and drill labor) and blasting (blast products and hole loading labor).

In all cases of modification, borehole diameter, powder factor, and weekly coal production (hence, weekly yardage broken) are assumed to remain constant. Therefore, all costs represent the average weekly cost to apply the modification under these assumptions.

3. Results and Discussion

Cost calculations for drilling and blasting for each decrease in charge weight per delay for the three methods of mining are found in Appendix A. Hole layouts showing the initiation sequence of individual charge detonation for the various cases are presented. Overburden and parting layers are treated separately for each mining method. Appendix B presents the methodology of cost calculation and the application of cost curves for the use in determining drilling and blasting costs of a mine property.

Tables 6 through 8 summarize the blast design (physical or technical changes made) for each modification. Case A represents the unrestricted case (or blast design under normal circumstances for blast site at a distance greater than D_{max} from a structure).

Tables 9 through 11 show the calculated cost per cubic yard for each charge weight per delay corresponding to distance values for the four levels of ground motion. These dollar values represent the average cost of fragmentation per cubic yard with the weekly unit costs shown on Table 5 by case (or modification) for the three methods of mining. All figures are labeled as weekly costs, but the cubic yard costs are time independent. These data points are plotted in Figures 3 through 9, each figure representing a set of cost curves (each curve associated with a level of ground motion) for a specified wasterock layer. For selected layers, an effort was made to show a cost comparison for two alternative blast designs for two points along

Table 6. Summary of Blast Designs For Typical Shot (Case A) and Modifications Made (Following Cases) For Overburden and Parting Layer Shots in Contour Strip Mining Method (Type 1).

CASE	LB. ANFO PER DELAY	BURDEN x SPACING x DEPTH (FT)	FRAGMENTATION VOLUME (CY) PER HOLE PER SHOT	NO. HOURS PER SHOT	ROHS x HOLES IN ROW	NO. SHOTS PER WEEK	NO. DECKED CHARGES	NO. LIFTS
OVERBURDEN								
A	630	13 x 15 x 60	433	40	5 x 8	2	1	1
B	500	11 x 14 x 60	342	32	4 x 8	3	1	1
C	250	11 x 14 x 60	342	32	4 x 8	3	2	1
D	100	11 x 14 x 60	342	20	4 x 5	5	5	1
E	36	9 x 10 x 30	100	28	4 x 7	12	4	2
F	25	9 x 8 x 30	80	18	3 x 6	24	5	2
G	10	6 x 6 x 20	27	30	5 x 6	30	4	3
H	7	5 x 7 x 15	19	35	5 x 7	36	4	4
PARTING								
A	480	12 x 12 x 45	240	27	3 x 9	4	1	1
B	350	10 x 10 x 45	167	30	3 x 10	5	1	1
C	300	9 x 10 x 45	150	28	4 x 7	6	1	1
C-1	300	11 x 13 x 45	238	35	5 x 7	3	2	1
D	200	10 x 12 x 45	200	21	3 x 7	6	2	1
E	80	9 x 11 x 45	165	28	4 x 8	6	4	1
F	36	7 x 9 x 23	53	40	5 x 8	12	3	2
G	25	7 x 9 x 23	53	27	3 x 9	18	4	2
H	10	6 x 6 x 15	20	30	5 x 6	42	4	3
I	7	5 x 6 x 15	17	20	4 x 5	42	4	3

Table 7. Summary of Blast Designs For Typical Shot (Case A) and Modifications Made (Following Cases) For Overburden and Parting Layer Shots in Area Strip Mining Method (Type 2).

CASE	LB. ANFO PER DELAY	BURDEN x SPACING x DEPTH (FT)	FRAGMENTATION VOLUME (CY) PER HOLE PER SHOT	NO. HOLES PER SHOT	ROWS x HOLES IN ROW	NO. SHOTS PER WEEK	NO. DROCKED CHARGES	NO. LIFTS
OVERBURDEN								
A	810	27 x 30 x 60	1800	30	5 x 6	4	1	1
B	700	25 x 28 x 60	1556	35	5 x 7	4	1	1
C	405	27 x 30 x 60	1800	30	5 x 6	4	2	1
D	203	27 x 30 x 60	1800	30	5 x 6	4	4	1
E	100	22 x 22 x 60	1076	20	4 x 5	10	5	1
F	36	16 x 18 x 30	320	28	4 x 7	24	4	2
G	25	14 x 14 x 30	218	30	5 x 6	33	4	2
H	10	10 x 12 x 20	89	35	5 x 7	70	4	3
I	7	9.5 x 11 x 20	77	20	4 x 5	140	5	3
PARTING								
A	85	11.5 x 13 x 20	111	130	10 x 13	5	1	1
B	60	10 x 10 x 20	74	80	10 x 8	12	1	1
C	36	7 x 8.5 x 20	44	130	10 x 13	13	1	1
C-1	30	10 x 10 x 20	74	50	5 x 10	19	2	1
D	25	8 x 10.5 x 20	62	48	6 x 8	24	2	1
E	10	6 x 8 x 20	36	32	4 x 8	61	3	1
F	7	8 x 7 x 20	42	20	4 x 5	84	5	1

Table 8. Summary of Blast Designs For Typical Shot (Case A) and Modifications Made (Following Cases) For Overburden and Parting Layer Shots in Contour Strip/Area Strip Mining Method (Type 3).

CASE	LD. ANFO PER DELAY	BURDEN x SPACING x DEPTH (FT)	FRAGMENTATION VOLUME (CY) PER HOLE PER SHOT	NO. HOLES PER SHOT	HOLES x HOLES IN ROW	NO. SHOTS PER WEEK	NO. DECKED CHARGES	NO. LIFTS
OVERBURDEN								
A	450	17 x 17 x 50	535	50	5 x 10	1	1	1
B	300	12 x 15 x 50	333	81	9 x 9	1	1	1
C	150	12 x 15 x 50	333	40	5 x 8	2	2	1
D	100	15 x 16 x 50	444	30	5 x 6	2	4	1
E	75	14 x 16 x 50	415	15	3 x 5	3	5	1
F	50	11 x 13 x 50	265	20	4 x 5	5	5	1
G	36	9 x 12 x 50	200	20	4 x 5	6	5	1
H	25	10 x 12 x 25	111	35	5 x 7	7	4	2
I	10	7 x 9 x 25	58	20	4 x 5	23	5	2
J	7	6 x 7 x 25	39	20	4 x 5	34	5	2
PARTING								
A	225	12 x 14 x 30	187	30	3 x 10	3	1	1
B	175	11 x 12 x 30	147	28	4 x 7	4	1	1
C	100	11 x 13 x 30	159	21	3 x 7	5	2	1
D	50	9 x 11 x 30	110	30	5 x 6	5	3	1
D-1	50	7 x 10 x 30	39	35	5 x 7	12	1	2
E	36	9 x 12 x 30	120	28	4 x 7	5	4	1
E-1	36	7 x 8 x 15	31	45	5 x 9	12	1	2
F	25	9 x 10.5 x 30	105	20	4 x 5	8	5	1
F-1	25	9 x 9 x 15	45	30	5 x 6	12	2	2
G	10	6 x 8 x 15	27	27	3 x 9	24	3	2
H	7	5 x 6 x 15	17	27	3 x 9	36	3	2

the 2.0 in/sec curve and three points along the curves between distance values below 900 feet. These points correspond to Cases D, D-1, E, E-1, F, and F-1, in Tables 8 and 11 for the parting layer of the contour strip/area strip method.

The cost to blast given a set rate of production and blasthole diameter, while decreasing charge weight per delay, increases exponentially as the distance, D, approaches the 300 foot regulatory limit. The rate of cost increase is a function of technology applied to the blast design associated with blasthole diameter. For large size holes containing generally high charge weights using wider spacings, modifications are not so severe at D values slightly less than D_{max} . More flexibility in design alternatives are available to keep the rate of cost increase small over a large D range. For smaller diameter blastholes, modifications required as charge weights decrease tend to increase this rate of cost increase at D slightly less than D_{max} . However, for D=300 feet, cost increase relative to the unrestricted case for large diameter holes is considerably greater than for small holes. From Tables 9 through 11 for worst case conditions (0.25 in/sec), a 300% increase in cost is shown for the 5 inch hole used for the parting layer of the area strip. A 700% increase from Case A to Case I for the overburden of the same mining type results from blasting with a 9½ inch hole. The remaining four blasting situations, each using a 7¼ inch hole, show between a 550% to a 640% increase from initial Case A to the cost to blast at D=300 feet.

Irrespective of hole diameter, the nature of modifications (or combinations thereof) applied to design can minimize the cost increase rate for decreasing distance values. Three basic levels of modifications are considered in this model. Each level is applied in order with decreasing D. The D value at which a jump to the next level occurs depends on: 1) the severity of total charge weight reduction, and 2) the cost to design within the current level with charge weight decreasing relative to the cost to redesign using a different modification. The levels are as follows:

- Level 1: Reduction of burden and spacing for a constant length of hole and full column loading of explosives.
- Level 2: Separating the full column load into decks.
- Level 3: Benching the wasterock layer into lifts, and combining decking with a reduction in hole pattern.

Tables 6 through 8 show these successive steps used as required in blast design modifications.

(1) Reduction of Burden and Spacing

In practice, as a blast site approaches a structure, the first modification to design is a reduction in the hole spacings to maintain a constant powder factor with a lower charge weight per delay. As a certain powder factor and production rate must be maintained, the lower yardage fragmented per hole requires an increased number of holes to be drilled per shot. This increases drilling costs substantially (Cases B and C, contour strip, parting layer; refer to Figure 4, dashed lines and also Appendix A). There are, however, two limiting conditions to

Table 9. Total Weekly Drilling and Blasting Costs Per Cubic Yard For Various Charge Weights of Explosives Per Delay (W) Calculated For Distance (D, feet) From Shot - Contour Strip (Type 1).

CASE	GROUND MOTION LEVEL (in/sec - 95% of time v will be less than indicated)											
	2.0			1.0			0.5			0.25		
	W	D	\$/CY	W	D	\$/CY	W	D	\$/CY	W	D	\$/CY
OVERBURDEN												
A	630	1255	.209	630	1506	.209	630	2384	.209	630	2937	.209
B	500	1118	.237	500	1342	.237	500	2124	.237	500	2616	.237
C	250	791	.249	250	949	.249	250	1502	.249	250	1850	.249
D	100	500	.292	100	600	.292	100	950	.292	100	1170	.292
E	36	300	.496	36	360	.496	36	570	.496	36	702	.496
F				25	300	.618	25	475	.618	25	585	.618
G							10	300	1.165	10	370	1.165
H										7	300	1.436
PARTING												
A	480	1095	.296	480	1315	.296	480	2081	.296	480	2563	.296
B	350	935	.364	350	1123	.364	350	1777	.364	350	2189	.364
C	300	866	.381	300	1039	.381	300	1645	.381	300	2027	.381
C-1	300	866	.303	300	1039	.303	300	1645	.303	300	2027	.303
D	200	707	.349	200	849	.349	200	1343	.349	200	1655	.349
E	80	447	.442	80	537	.442	80	850	.442	80	1046	.442
F	36	300	.691	36	360	.691	36	570	.691	36	702	.691
G				25	300	.712	25	475	.712	25	585	.712
H							10	300	1.237	10	370	1.237
I										7	300	1.922

Table 10. Total Weekly Drilling and Blasting Costs Per Cubic Yard For Various Charge Weights of Explosives Per Delay (W), Calculated For Distance (D, feet) From Shot - Area Strip (Type 2).

CASE	GROUND MOTION LEVEL (in/sec - 95% of time v will be less than indicated)											
	2.0			1.0			0.5			0.25		
	W	D	\$/CY	W	D	\$/CY	W	D	\$/CY	W	D	\$/CY
OVERBURDEN												
A	810	1423	.058	810	1708	.058	810	2704	.058	810	3330	.058
B	700	1323	.062	700	1587	.062	700	2513	.062	700	3096	.062
C	405	1006	.061	405	1207	.061	405	1912	.061	405	2355	.061
D	203	712	.065	203	855	.065	203	1354	.065	203	1667	.065
E	100	500	.091	100	600	.091	100	950	.091	100	1170	.091
F	36	300	.143	36	360	.143	36	570	.143	36	702	.143
G				25	300	.223	25	475	.223	25	585	.223
H							10	300	.363	10	370	.363
I										7	300	.466
PARTING												
A	85	462	.212	85	554	.212	85	877	.212	85	1081	.212
B	60	387	.289	60	465	.289	60	736	.289	60	906	.289
C	36	300	.444	36	360	.444	36	570	.444	36	702	.444
C-1				30	329	.344	30	520	.344	30	641	.344
D				25	300	.399	25	475	.399	25	585	.399
E							10	300	.727	10	370	.727
F										7	300	.841

Table 11. Total Weekly Drilling and Blasting Costs Per Cubic Yard For Various Charge Weights of Explosives Per Delay (W) Calculated For Distance (D, feet) From Shot - Area Strip/Contour Strip (Type 3).

CASE	GROUND MOTION LEVEL (in/sec - 95% of time v will be less than indicated)											
	2.0			1.0			0.5			0.25		
	W	D	\$/CY	W	D	\$/CY	W	D	\$/CY	W	D	\$/CY
OVERBURDEN												
A	450	1060	.132	450	1273	.132	450	2015	.132	450	2482	.132
B	300	866	.177	300	1039	.177	300	1645	.177	300	2026	.177
C	150	612	.192	150	735	.192	150	1164	.192	150	1433	.192
D	100	500	.180	100	600	.180	100	950	.180	100	1170	.180
E	75	433	.202	75	520	.202	75	823	.202	75	1013	.202
F	50	353	.281	50	424	.281	50	672	.281	50	827	.281
G	36	300	.349	36	360	.349	36	570	.349	36	702	.349
H				25	300	.362	25	475	.362	25	585	.362
I							10	300	.666	10	370	.666
J										7	300	.972
PARTIAL												
A	225	750	.223	225	900	.223	225	1425	.223	225	1755	.223
B	175	661	.260	175	794	.260	175	1257	.260	175	1548	.260
C	100	500	.279	100	600	.279	100	950	.279	100	1170	.279
D	50	354	.398	50	424	.398	50	672	.398	50	827	.398
D-1	50	354	.473	50	424	.473	50	672	.473	50	827	.473
E	36	300	.391	36	360	.391	36	570	.391	36	702	.391
E-1	36	300	.552	36	360	.552	36	570	.552	36	702	.552
F				25	300	.461	25	475	.461	25	585	.461
F-1				25	300	.594	25	475	.594	25	585	.594
G							10	300	.960	10	370	.960
H										7	300	1.49

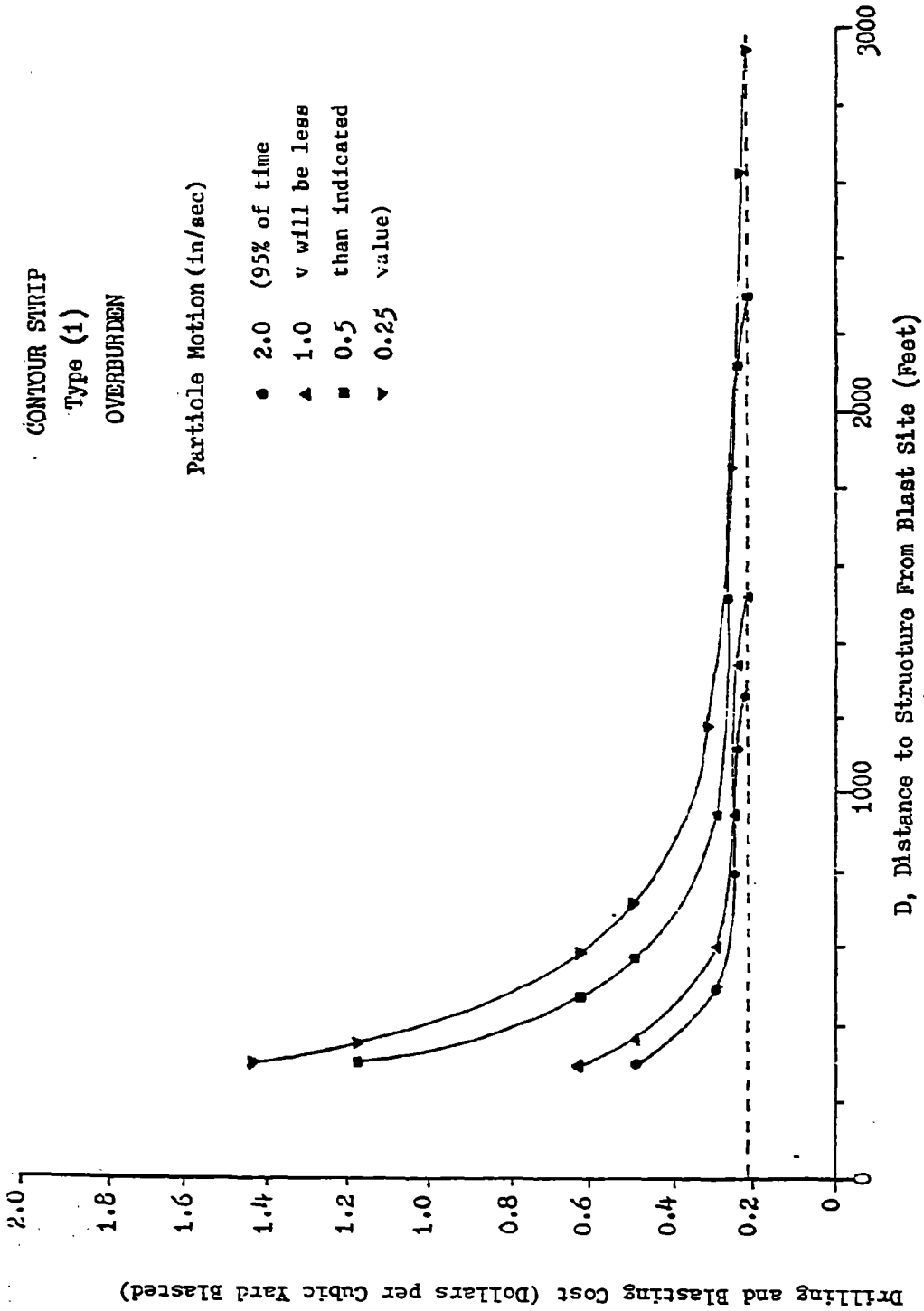


Figure 3. Total Weekly Drilling and Blasting Costs Per Cubic Yard Versus Distance From Blast Site For Four Levels of Ground Motion - Contour Strip (Type 1), Overburden Layer.

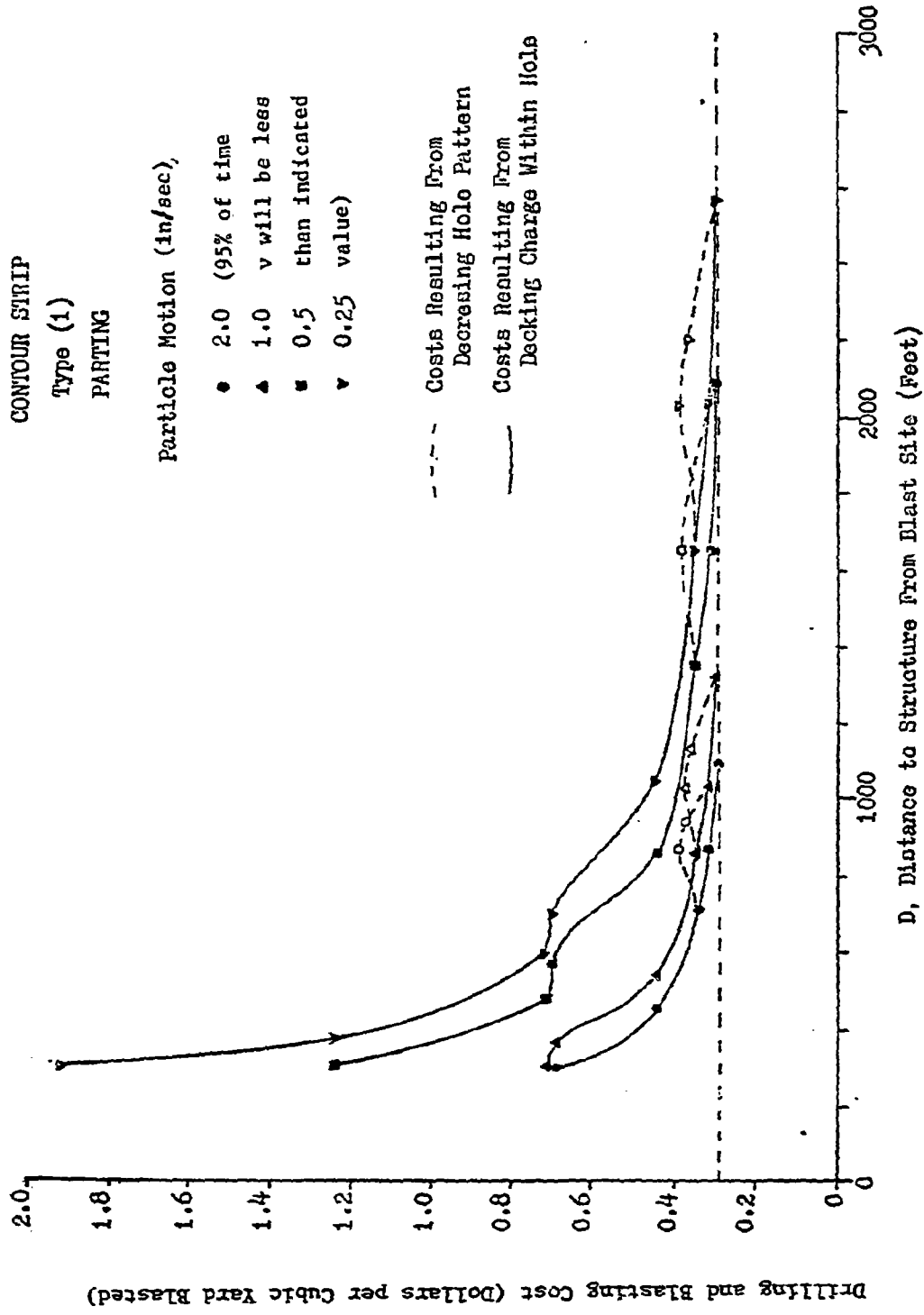
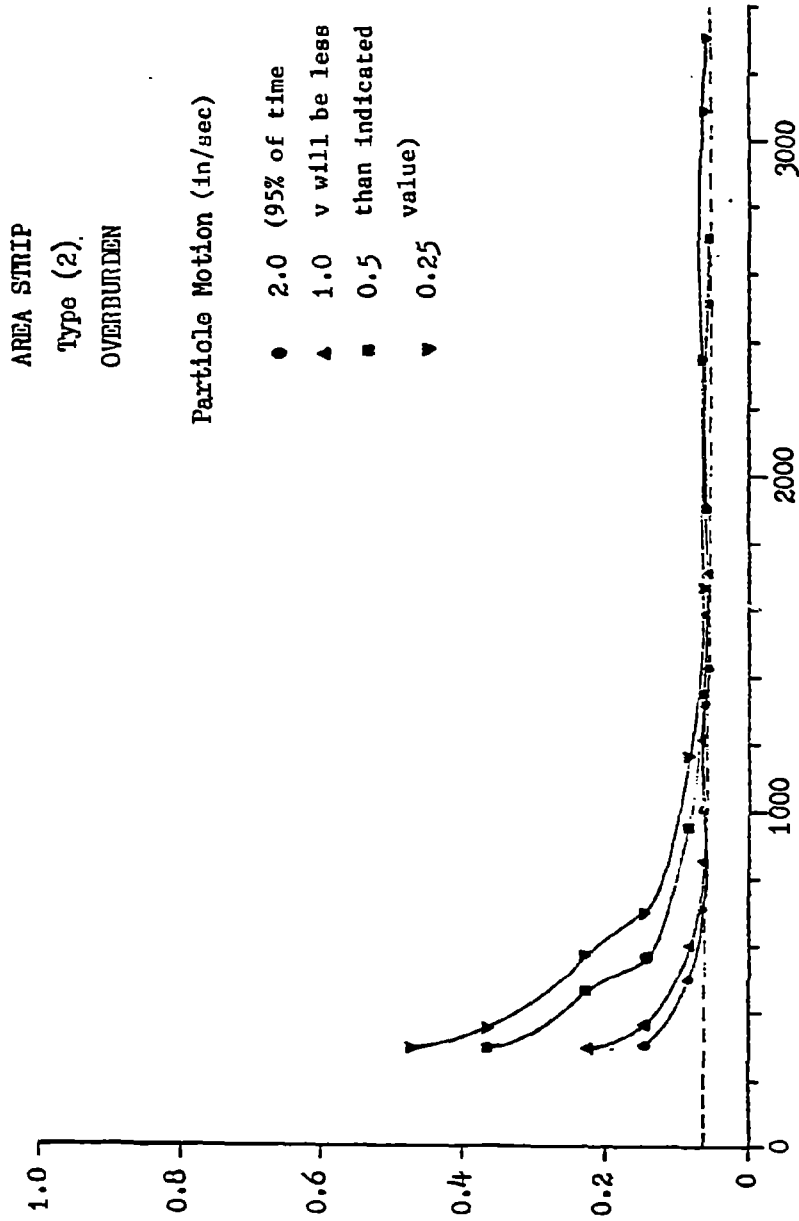


Figure 4. Total Weekly Drilling and Blasting Costs Per Cubic Yard Versus Distance From Blast Site For Four Levels of Ground Motion - Contour Strip (Type 1), Parting Layer.

Drilling and Blasting Cost (Dollars per Cubic Yard Blasted)



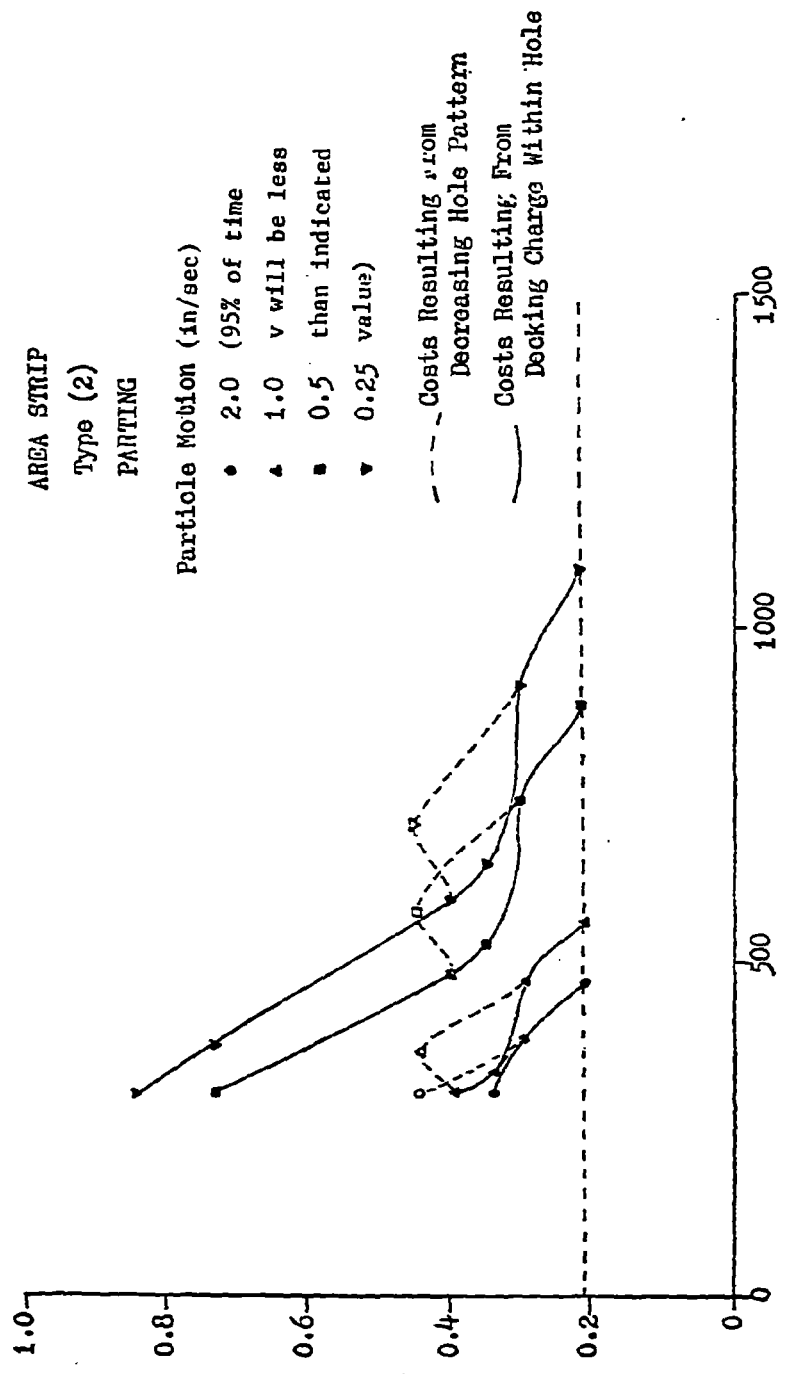
AREA STRIP
Type (2).
OVERBURDEN

Particle Motion (in/sec)

- 2.0 (95% of time)
- ▲ 1.0 v will be less
- 0.5 than indicated
- ▼ 0.25 value)

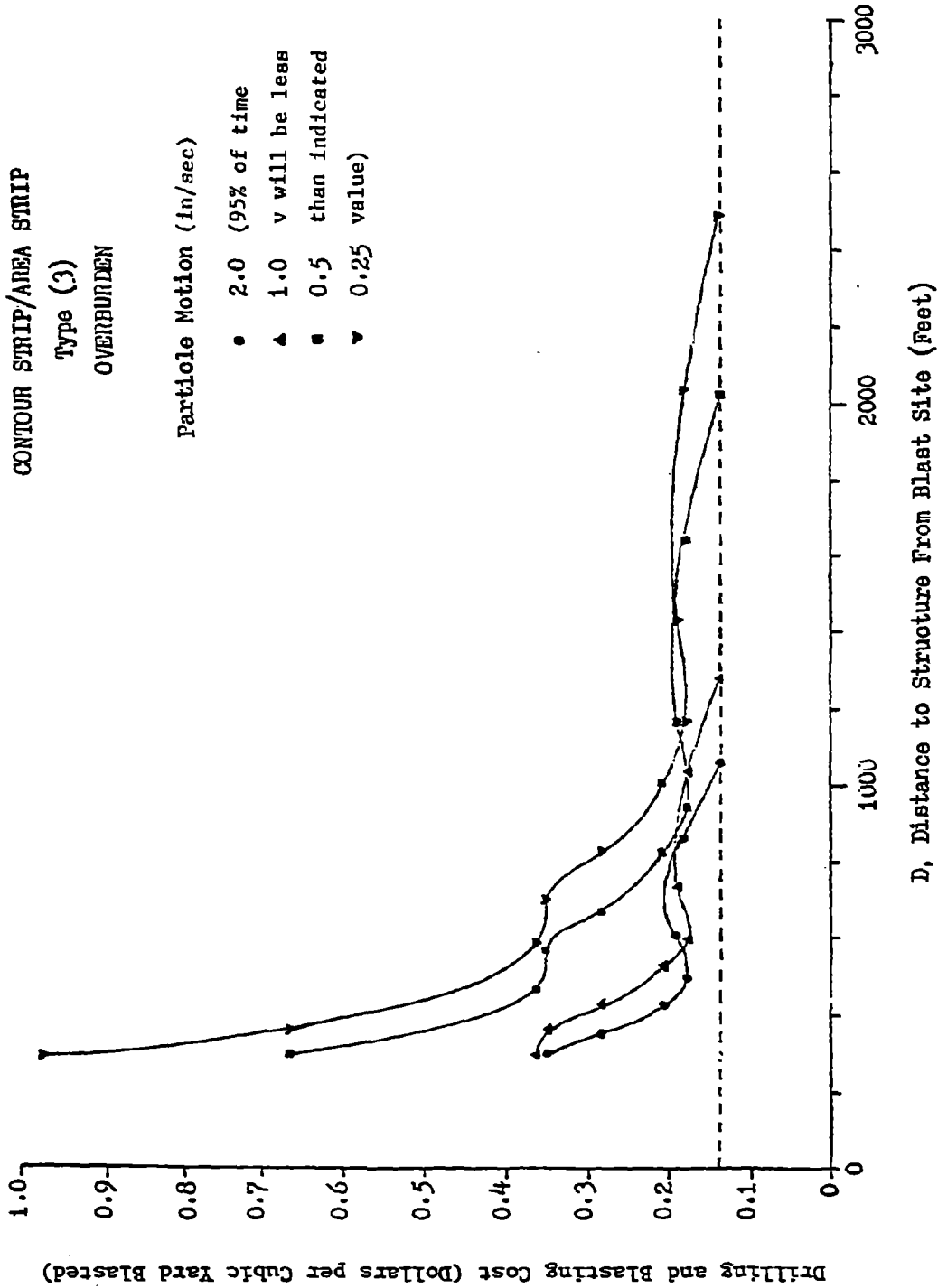
D, Distance to Structure From Blast Site (Feet)

Figure 5. Total Weekly Drilling and Blasting Costs Per Cubic Yard Versus Distance From Blast Site For Four Levels of Ground Motion - Area Strip (Type 2), Overburden Layer.



D, Distance to Structure From Blast Site (feet)

Figure 6. Total Weekly Drilling and Blasting Costs Per Cubic Yard Versus Distance From Blast Site For Four Levels of Ground Motion - Area Strip (Type 2). Parting Layer.



D, Distance to Structure From Blast Site (Feet)

Figure 7. Total Weekly Drilling and Blasting Costs Per Cubic Yard Versus Distance From Blast Site For Four Levels of Ground Motion - Contour Strip/Area Strip (Type 3), Overburden Layer.

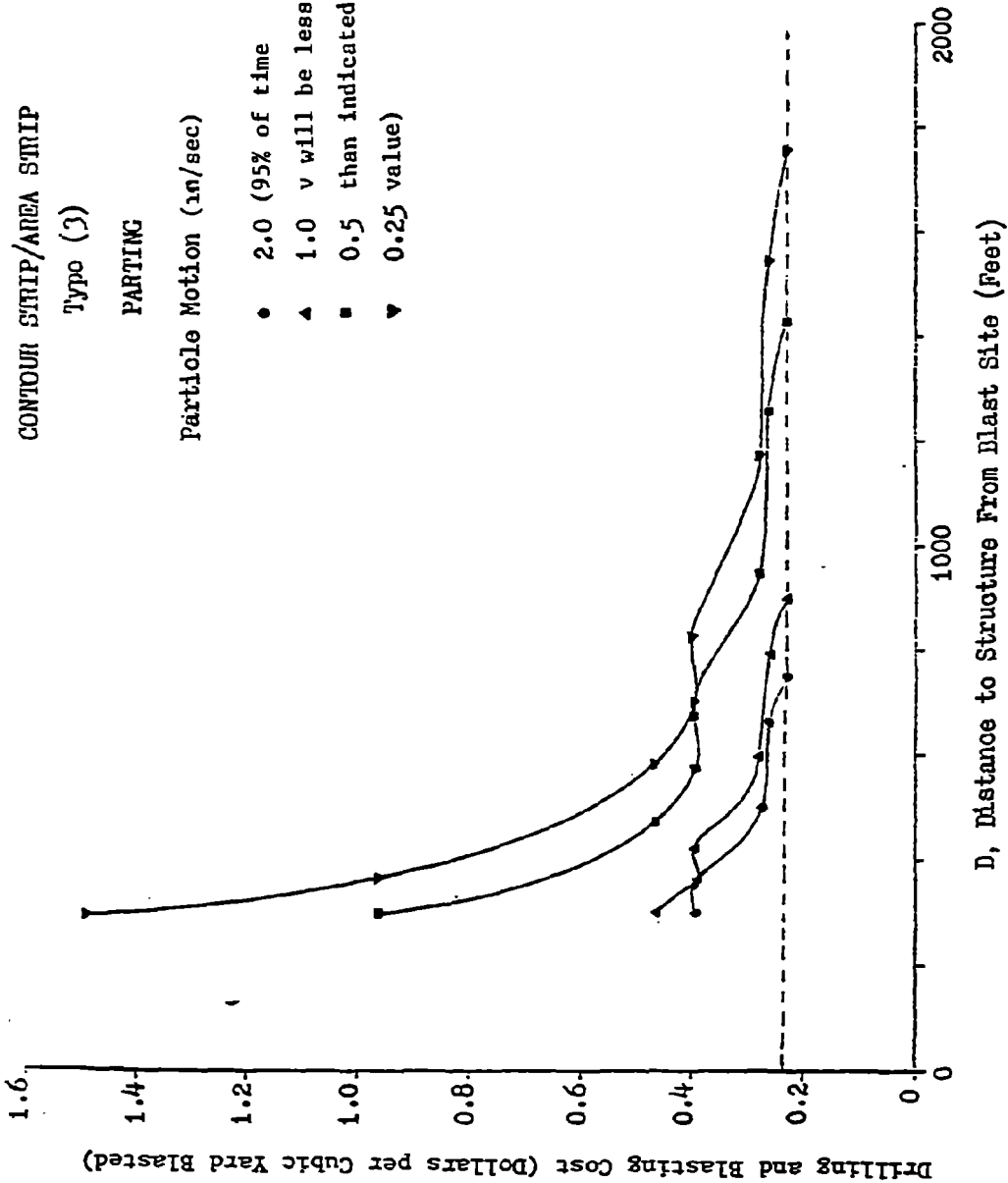
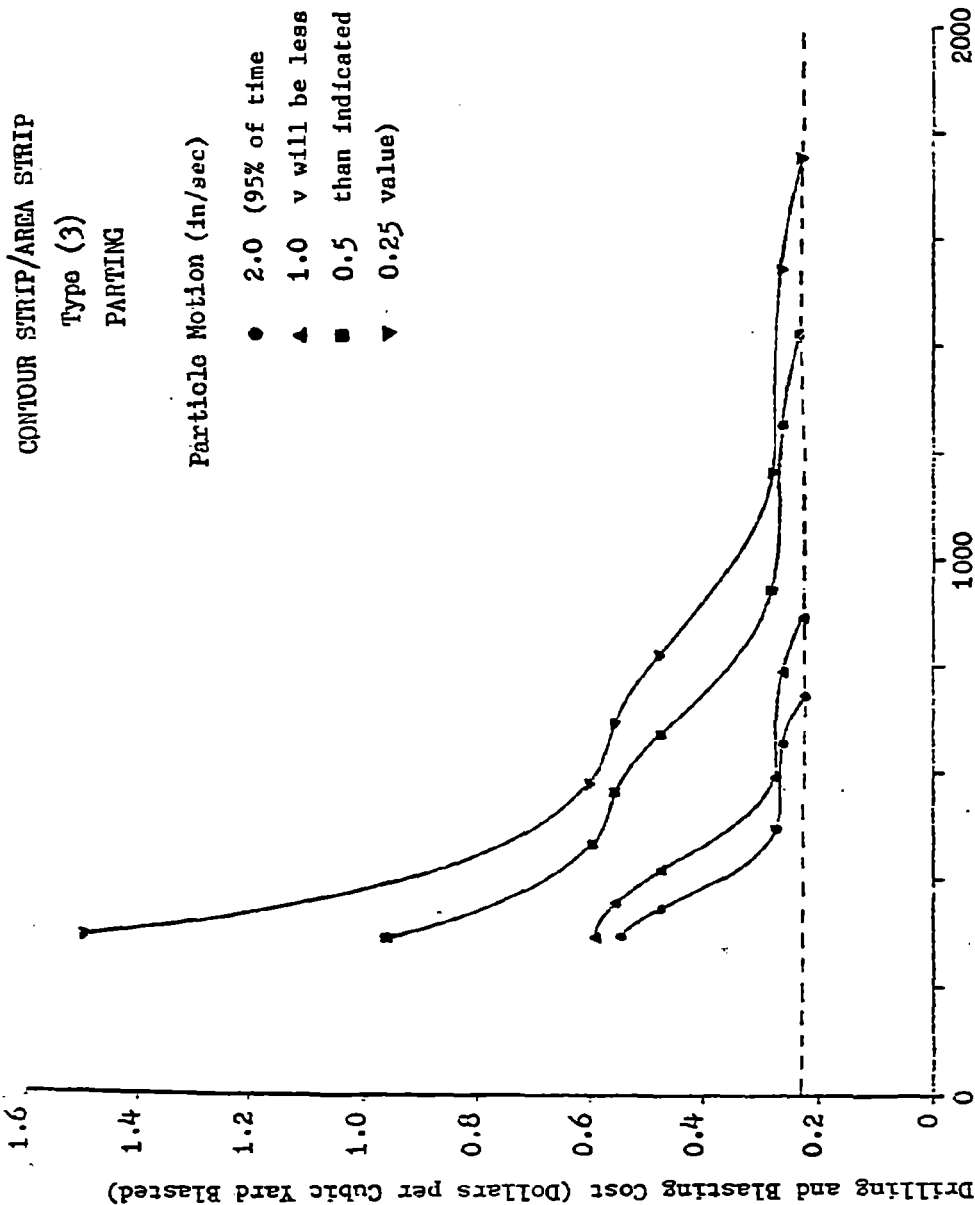


Figure 8. Total Weekly Drilling and Blasting Costs Per Cubic Yard Versus Distance From Blast Site For Four Levels of Ground Motion - Contour Strip/Area Strip (Type 3), Parting Layer.

CONTOUR STRIP/AREA STRIP
Type (3)
PARTING

Particle Motion (in/sec)

- 2.0 (95% of time)
- ▲ 1.0 v will be less
- 0.5 than indicated
- ▼ 0.25 value)



D, Distance to Structure From Blast Site (Feet)

Figure 9. Total Weekly Drilling and Blasting Costs Per Cubic Yard Versus Distance From Blast Site For Four Levels of Ground Motion - Contour Strip/Area Strip (Type 3), Parting Layer.

this level. This first is the poorer fragmentation resulting from a constantly shrinking explosive column in the hole and, second the cost relative to using decks. Fragmentation problems occur with tough caprock existing in the uppermost strata; explosive charges must remain sufficiently high within the hole for proper fragmentation near the top as well as uniformly throughout the hole. A severe drop in height of the powder column results in poor fragmentation. For small diameter blastholes, with low densities of loading (pounds of ANFO contained in one foot of borehole) this drop occurs rapidly.

(2) Decked Charges

It has been observed in the field, that the mine operator prefers to decrease hole spacings with charge weight restrictions rather than doubling or tripling delays within each hole by decking. The latter method requires redesign to insure single deck initiation with no overlap in delays. This can be tedious and time consuming. The limitation of delays available is often discouraging when large shots (total number of holes) is desired. Also, for safety reasons, hole loaders prefer to handle as few blasting caps as possible. Because of this reluctance, decking tends to be applied when fragmentation is a problem (as measured by bucket time at the face or wear on the bucket) or when drilling and blasting costs are notably high.

By decking charges, each deck containing a single delay, the cost increase of blasting with reduced charge weight per delay is limited to the additional costs of caps and primers with only a slight time increase to load decked holes. When the cost increase for hole spacing reduction becomes severe, the increase in rate is shown to level off for lower values of W (charge weight). This occurs in Figure 8 for cost values around \$0.40/cubic yard; the data points within this vicinity are a result of decking costs (see Appendix A). Figure 9 shows the rate increase for single column, decreased pattern spacing situation. Figure 4 shows a similar leveling off around \$0.70/cubic yard for data points at Cases F and G; both designs have the same burden and spacing, with G containing one more deck than F, resulting in a small cost increase. A similar slow rate of increase is noted in Figure 3, for Cases B, C, and D, all with the same pattern, but increasing number of decks.

The limitation to this level of modification is two fold; first is the limitation concerning the practical number of delays per hole such that the restriction on the shot size (limited to the number of delays available) is not too severe and does not require an unreasonable number of shots per day. The demand on drilling and hole loading time must be checked. The second limiting factor is the maximum hole volume available for the decked charges and stemming between decks as well as top holes stemming. Again,

small diameter holes are most sensitive to this factor and once the maximum number of decks (allowing for proper stemming) has been reached, further modifications are to reduce hole spacing. However, the rate of cost increase rises. Additionally, there is a practical limit of burden and spacing relative to hole length for design. Decreased burdens increase the chance of airblast from the free face as well as increase the possibility of downhole cut-off from rock shifting resulting from a too-close hole detonating.

(3) Benching Rock Layer

The ultimate design modification reduces total hole length to compensate for closer hole spacings. Benching increases all cost factors to a large degree and the total number of drill holes required per week can be very large. Although this design modification is feasible, observations of such practices in the field have been limited to: 1) benching excessively high walls for safety reasons, and 2) taking geologically contrasting rock units in separate benched blasts.

IV. APPLICATION OF COST CURVES

Figures 10 through 15 show the three permits selected for cost model application. Regional topography and demographic conditions surrounding each permit is presented. Each permit is shown subdivided into blocks (weekly or monthly) and each block represents the size of shots for that time period.

These blocked permits were employed to calculate the costs. Distances from the center of the blocks to the nearest residence were measured for each block. For a given restriction, say 1.0 in/sec, the cost associated with that distance was found from the appropriate Figure (3 through 9). The costs for all blocks were summed over the entire permit area and divided by the total number of blocks to attain an average drilling and blasting cost for the life of the permit. This sum was performed four times; once for each level of restriction, 2 through 0.25 in/sec.

Table 12 summarizes the average costs over the permit life of the three mining methods. The total cost per ton was calculated by applying the average stripping ratio to the cost per cubic yard.

Figure 16 presents a plot of total drilling and blasting costs per cubic yard versus level of ground motion for the three mining methods. Due to the size of the area strip permit, demographic conditions within the permit boundary do not affect blasting for a great majority of the blocks. The spatial relationship of dwellings around the contour strip, steep-sloped permit (Figures 10 and 11) is such that most distances scaled from the blast sites to nearby homes fall within the 1000 to 2000 foot range. This is the range in cost calculations

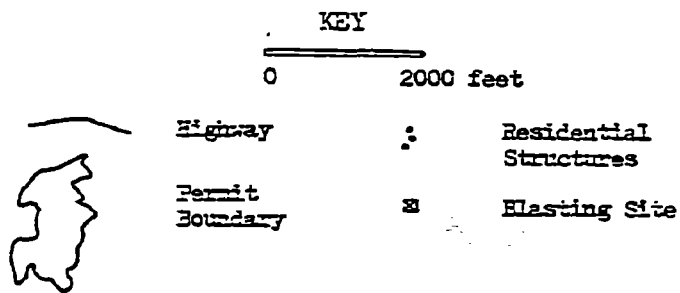
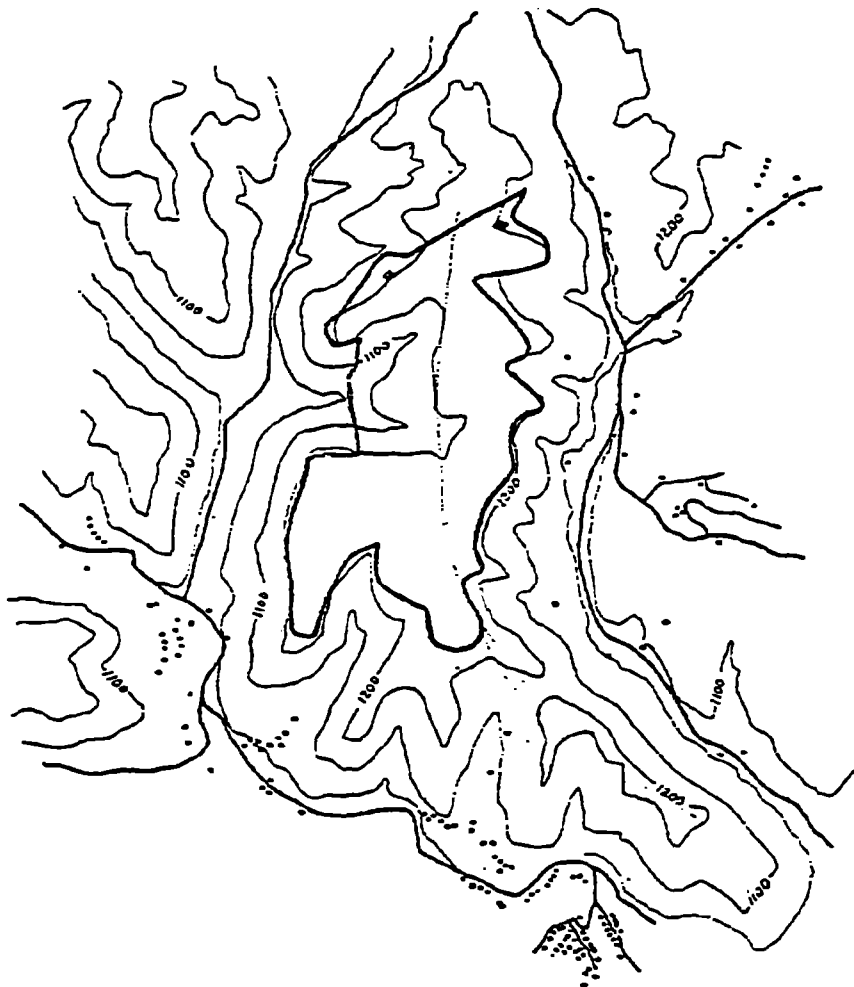


Figure 10 . Typical Permit Representing Contour Stripping Mining Method For Application of Cost Model (Type 1).

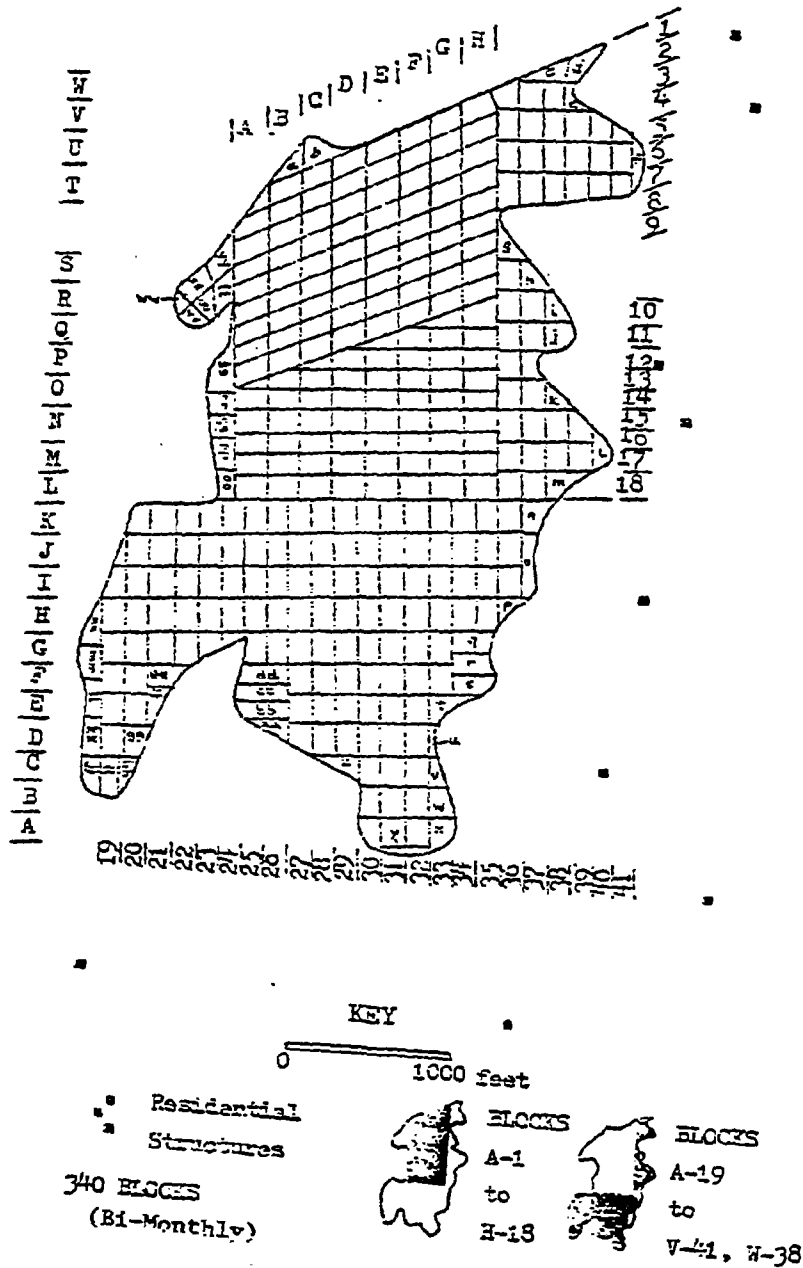


Figure 11. Contour Strip Mining Model Simulating the Volume of Wasterock Required For Fragmentation to Meet Monthly Coal Production.

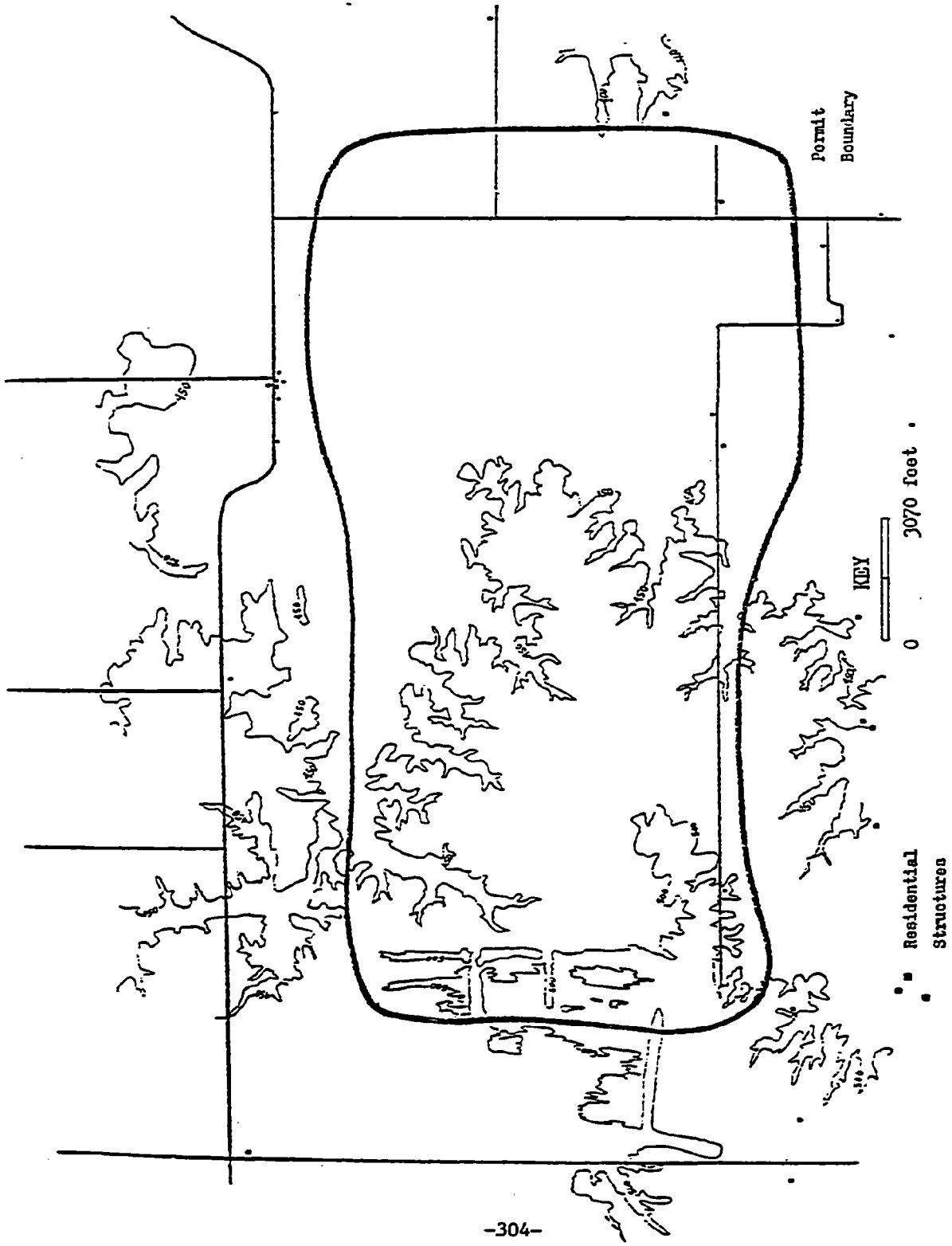


Figure 12. Typical Permit Representing Area Stripping Mining Method For Application of Cost Model (Type 2).

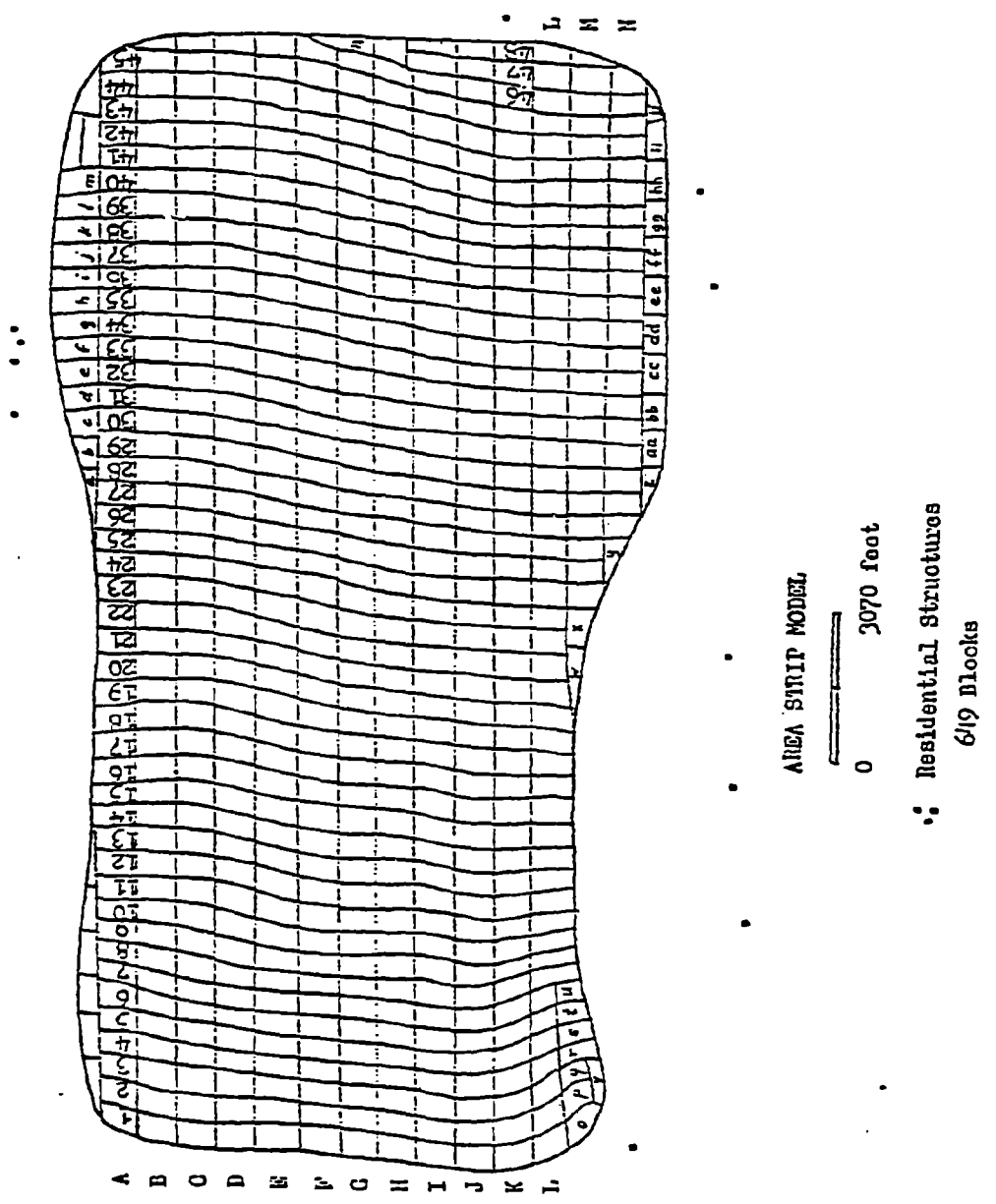


Figure 13. Area Strip Mining Model Simulating the Volume of Wasterock Required For Fragmentation to Meet Monthly Coal Production.

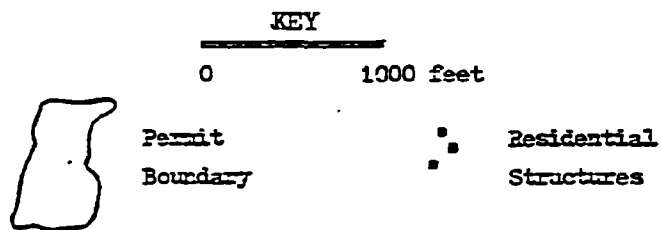
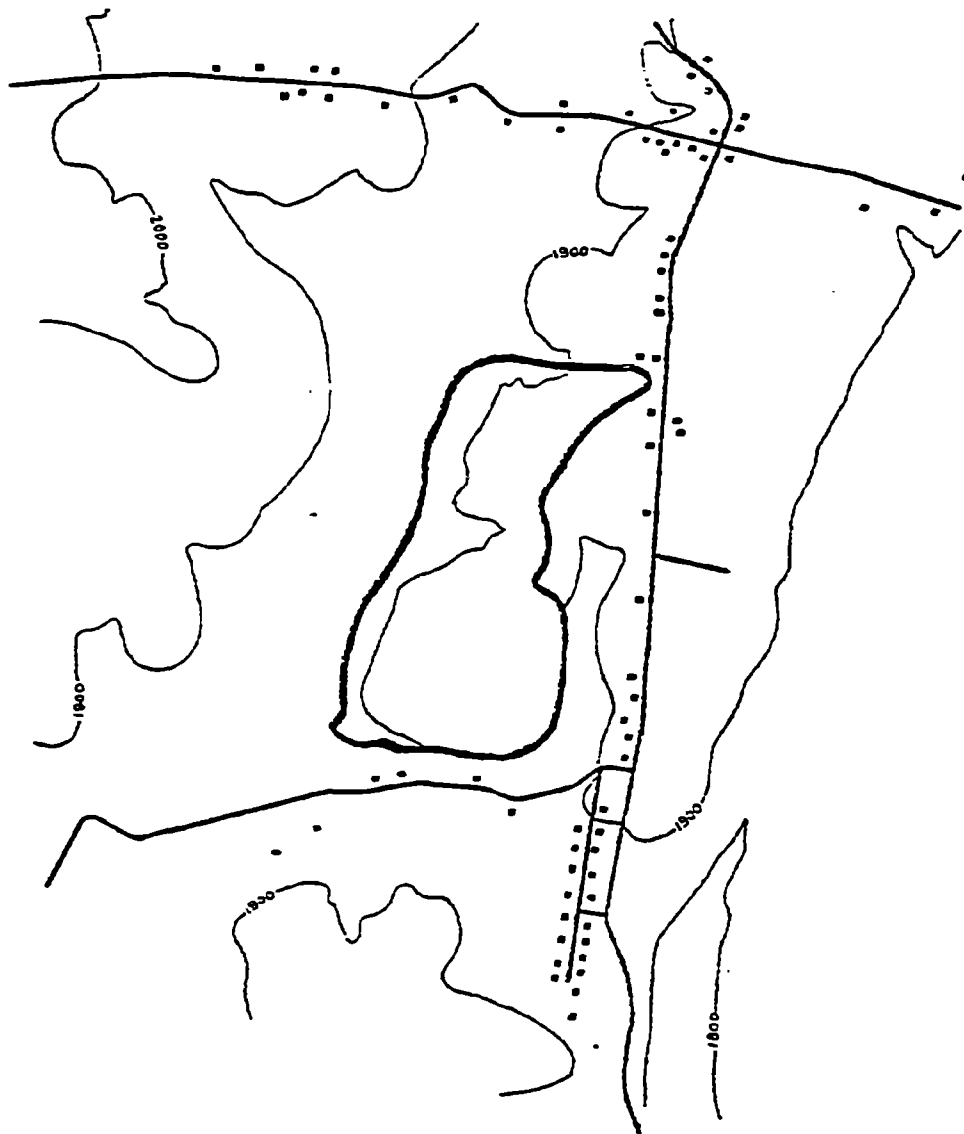
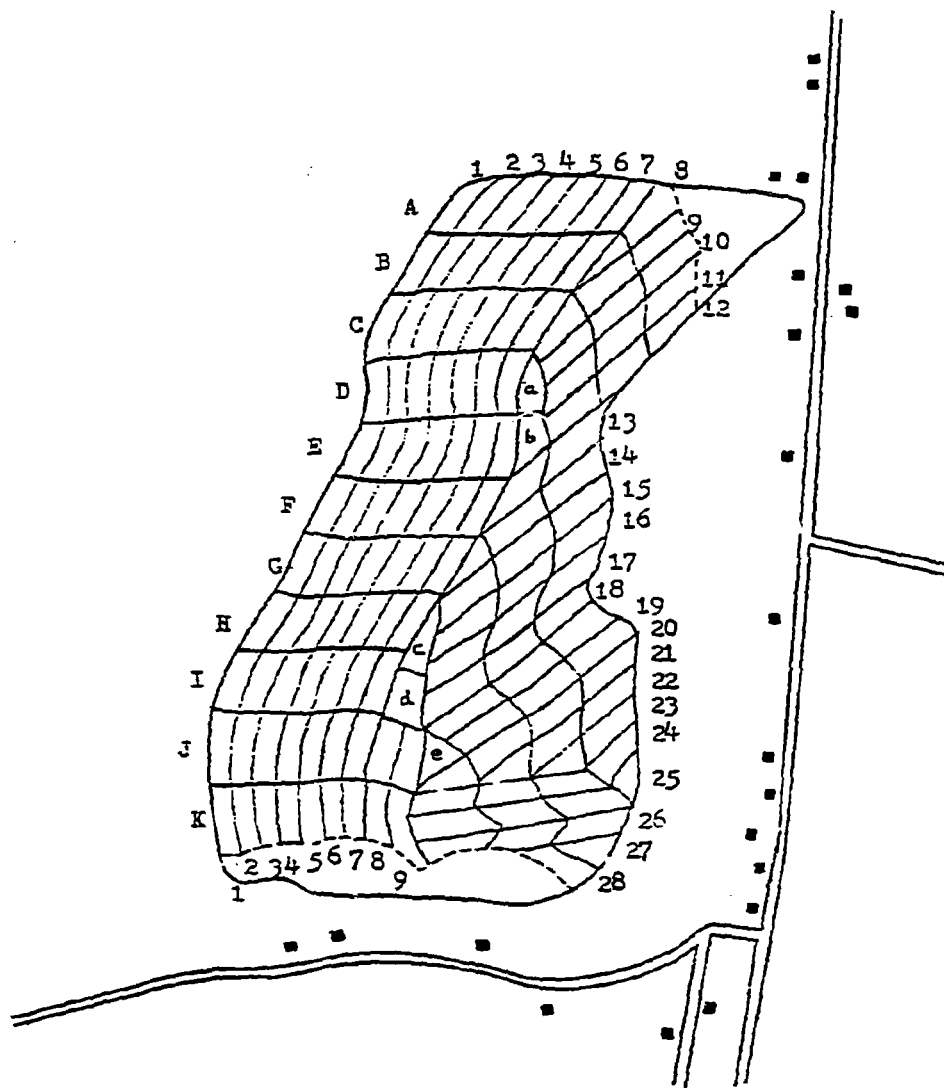


Figure 14 . Typical Permit Representing Contour Stripping/Area Stripping Mining Method For Application of Cost Model (Type 3).



0 500 feet
 ■ Residential Structures 145 BLOCKS (Weekly)

Figure 15. Contour Strip/Area Strip Mining Model Simulating the Volume of Wasterock Required For Fragmentation to Meet Weekly Coal Production.

Table 12. Summary of Total Drilling and Blasting Costs in Dollars per Cubic Yard (Column 1) and Dollars per Ton of Coal Mined (Column 2) for Blasts Designed to Comply with Four Levels of Ground Motion (1)

MINING METHOD	(in/sec - 95% of time v will be GROUND MOTION LEVEL less than indicated value)							
	2.0		1.0		0.5		0.25	
	1	2	1	2	1	2	1	2
CONTOUR STRIP Type (1)	0.267	3.872	0.271	3.930	0.304	4.408	0.334	4.843
AREA STRIP Type (2)	0.0966	1.546	0.0968	1.549	0.0979	1.566	0.0996	1.594
CONTOUR STRIP/ AREA STRIP Type (3)	0.217	3.754	0.235	4.066	0.321	5.553	0.389	6.730

- (1) The costs represent the average cost of fragmentation over the life of the permit.
- (2) These costs were calculated from the model which is based upon current practice. Powder factors for efficient breakage were obtained through interviews, but the charges per delay were chosen from Fig. V-2.

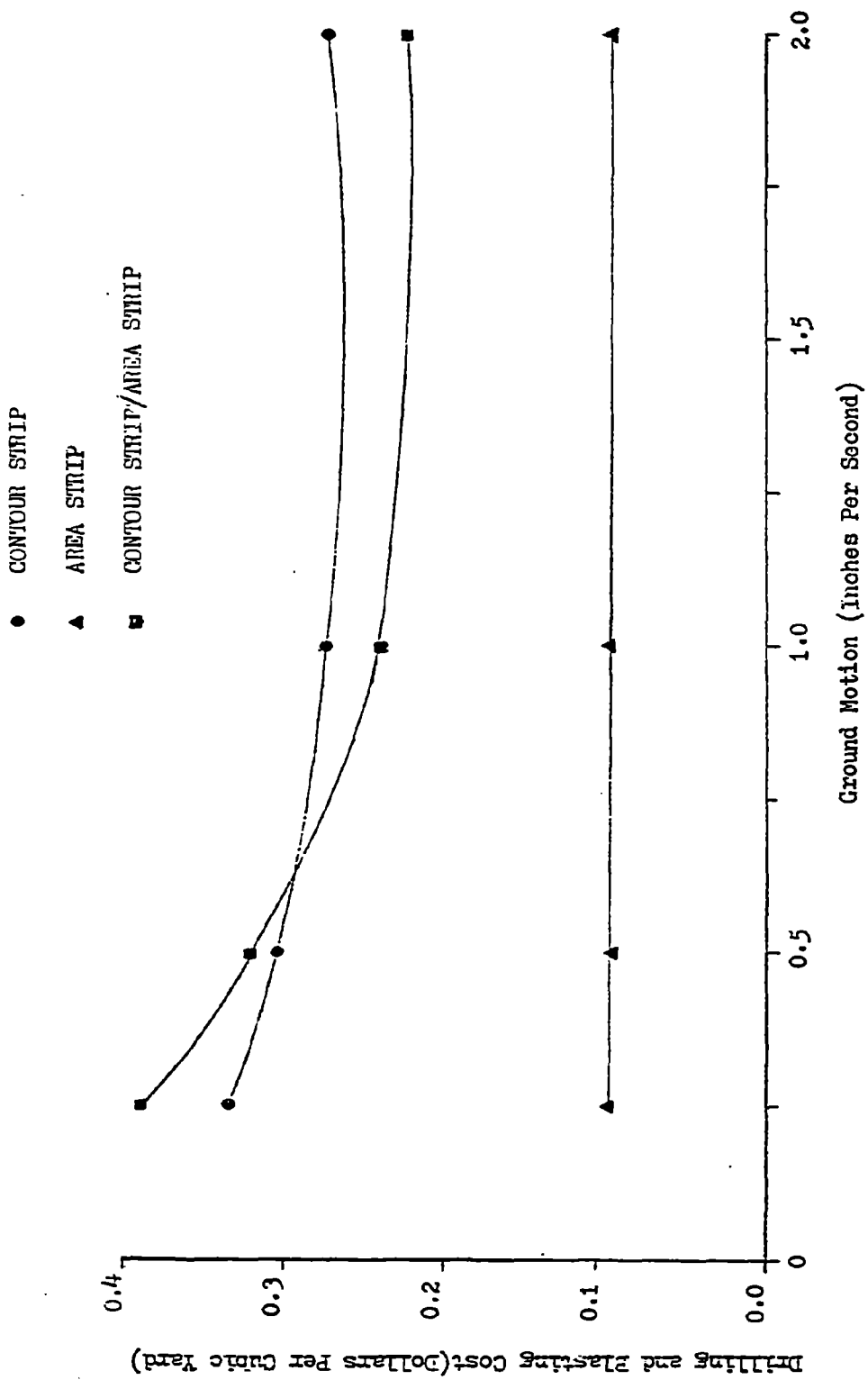
corresponding to Level 1 of modifications; slightly decreasing hole spacings to compensate for lowered charge weights per delay does not result in a great increase in total costs of blasting from 2.0 to 0.25 i.p.s. in this case.

The distribution of dwellings around the contour strip/area strip mine model, although along two edges of the permit, are close to the boundary. The distances from all blocks to the homes range from 500 to 1200 feet. As shown in the cost curves (Figures 7, 8, and 9), the rate of increase for total costs is fairly substantial within this range.

The potential for national impact as drilling and blasting costs increase as a function of decreasing levels of ground motion can be assessed by assuming that national production figures can be divided among the three mining scenarios presented. As approximately 61% of the 1977 surface coal production has been taken into account within the cost models, the remaining 39% west of the Mississippi River has not been fully assessed. However, based on field observations in 1978, the potential for blasting to impact surrounding residents and communities within Western coal fields was not significant relative to Eastern U.S. regions. Western mining areas tend to be remote. As the area strip permit model used for cost calculations typifies a large area mining situation and the demographic conditions presented a conservative distribution, the cost increase factors may well apply to Western coal mining in addition to Mid-Western and outlying Appalachian regions. Using 1977 surface coal production figures (total U.S. production of 416,945,000 net tons) and referring to Table 2, the total surface production to which the area strip cost model may be applied is 58% (or 19% from Table 2 plus 39% from Western coal); contour stripping production accounts for 20%, while contour strip/area strip is 22%.

From Figure 16, two general observations can be made concerning national impact of the costs calculated. The first observation concerns cost for all three methods from 2.0 to 1.0 in/sec. The increase within this range appears to be of little consequence. This fact was substantiated during Phase I site investigations in 1978. An intense study of drilling and blasting costs for five mining companies showed no cost increase from 1977 (blasting in compliance with a 2.0 in/sec standard) to 1978 (complying with 1.0 in/sec). The costs used for comparison were average monthly costs to drill and blast as defined in this study, and obtained directly from mine accounting books and records.

The second observation is the general lack of impact for varying levels of ground motion restriction to increase costs for the large area strip model. A minor percentage (3%) increase in costs is noted when blast levels change from 2.0 to 0.25 in/sec. Large area strip mines (type 2), including those in the West, account for 58% of surface coal production in the U.S.



(95% of time v will be less than indicated value)

Figure 16. Total Drilling and Blasting Costs Per Cubic Yard Versus Level of Ground Motion For Three Methods of Surface Coal Mining as Calculated For Blast Design Modifications and Applied to Representative Mining Permits.

The remaining 42% of surface production is modeled by the upper two curves in Figure 16. However, the only cost increase of significance is for that below 1.0 in/sec. Contour stripping (Type 1), which represents 20% of surface production in the U.S., is impacted with a 12% cost increase when blasting restrictions are tightened from 1.0 to 0.5 in/sec; lowering the level one step further to 0.25 in/sec increases costs an additional 10%. Contour strip/area strip mining (Type 3) is represented by 22% of the total surface production. Between 1.0 and 0.5 in/sec, costs increase 37%. From blast level 0.5 to 0.25 in/sec the cost increase rises at an even steeper rate, or a 21% increase over this interval.

V. CONCLUSIONS

Mine site investigations during 1978 and 1979 provided technical and economic data to develop cost models used to simulate drilling and blasting in surface coal mining. Over 42 mining companies were investigated and the data obtained for mining operations were averaged to develop three mining scenarios representative of surface coal mining in the Eastern U.S.

Blast configurations, designed to comply with 2.0, 1.0, 0.5, and 0.25 inches per second resultant velocity of ground motion, were developed with the scale distance data presented by Lucole and Dowding (1977) to final appropriate charge weights per delay. Modifications in design for area strip, contour strip, and combined area strip/contour strip mining methods were developed as hypothetical blast blocks moved from various distances to the regulatory limit of 300 feet from a structure. Costs of blasting with decreasing amounts of explosive charge per delay for all three methods increased exponentially as a function of decreasing distance. The rate of increase reflects the technical nature of design modifications applied to compensate for the decrease in charge per delay, as well as the borehole diameter used in blasting.

For blastholes ranging from 5 to 9½ inches in diameter, shots with smaller holes were most sensitive to cost increases over a wider range of critical distances. Shots with larger diameter holes did not show a significant cost increase until distance values from a dwelling to the blast site fell below 900 feet.

The costs of drilling and blasting under four levels of ground motion restriction were then applied to three permits representative of housing proximity for the three methods of mining to compute an average permit cost for drilling and blasting under various charge weight restrictions were then calculated. Depending on the demographic conditions surrounding the permit, the impact of regulatory limits can increase costs significantly.

A large percentage of the U.S. surface coal production (58% in 1977) is extracted from relatively large area strip mining methods. The model simulating area stripping can be applied in general to the area strips in the Western coal fields as well as to those mines in the Mid-West and upper and lower flanks of Appalachia. Demographic conditions

and blasting techniques are assumed to be similar for all regions utilizing this method of coal extraction.

For contour strip and combined contour strip/area strip mining methods, permits are generally small in size (compared to area strips) and the potential for the existence of a dwelling nearby a blast site to impact the costs of fragmentation at any location within the permit is great. The cost increase associated with blasting at lower levels of ground motion is significant, particularly for Type 3 at levels less than 1.0 in/sec. The contour strip/area strip mining method particular to the rolling hill terrain observed in Northern and Southern Appalachia are impacted to a great degree due to the higher populations existing in these regions.

In summary, a 3% increase in drilling and blasting costs was computed for large area strip mining when blasting levels were lowered from 2.0 to 0.25 in/sec. This increase factor affects approximately 58% of the surface coal production. Twenty percent of the total coal production extracted from steep slope regions of Appalachia is impacted with a 12% drilling and blasting cost increase for blasting standards lowered from 1.0 to 0.5 in/sec; further reduction to 0.25 in/sec shows an additional 10% cost increase. Contour strip/area strip methods maintain a cost increase factor of 37% and 21% between the levels of 1.0 to 0.5 in/sec and 0.5 to 0.25 in/sec respectively.

Two general observations can be made concerning national impact of costs calculated. The first observation concerns cost for all three methods from 2.0 to 1.0 in/sec. The increase within this range appears to be of little consequence. This fact was substantiated during Phase I site investigations in 1978. An intense study of drilling and blasting costs for five mining companies showed no cost increase from 1977 (blasting in compliance with a 2.0 in/sec standard) to 1978 (complying with 1.0 in/sec). The costs used for comparison were average monthly costs to drill and blast as defined in this study, and obtained directly from mine accounting books and records.

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NOTE: THE APPENDICES FOR SECTION 2: TECHNICAL AND COST ISSUES, HAVE BEEN BOUND IN A SEPARATE VOLUME, AND ARE AVAILABLE ON REQUEST FROM NORTHWESTERN UNIVERSITY.

SECTION THREE

CONCLUSIONS AND
IMPLICATIONS FOR
POLICY AND FUTURE RESEARCH

I. AN OVERVIEW OF THE CONCLUSIONS

The analyses of this study provide a broad perspective of blasting as an issue, both for communities and mines. While some specific implications for policy and future research are suggested below, these must be considered from a broad contextual perspective which takes into account and develops proper balance among the multiple, interactive factors and dynamics affecting both communities and mines. Without such a broad perspective, disaggregated and potentially conflicting and dysfunctional conclusions might be drawn from different aspects of the analyses.

Several broad conclusions can be drawn from this study.

- 1) Blasting per se is not the major issue either for communities near surface mines or for the surface mine companies.
- 2) The number of instances where severe cracking or annoyance impacts on community do occur is quite small relative to the total number of mines, the total number of blasts, or to the total number of residents near surface mines. Nonetheless, where such instances do occur, the impact can be quite severe for community residents who are immediately involved.
- 3) Blasting/drilling cost curves tend to rise significantly at intervals below 1.0 particle velocity, in/sec. Of course, the level of particle velocity required at the point of a blast to insure 1.0 or less particle velocity at a structure away from the blast will depend on the distance between the blast site and the structure. Thus, it follows that cost curves at intervals below 1.0 particle velocity are inversely related to the size of a permit area. It further follows that the cost impact will tend to be more significant for small than for large mines; and in steep or sloping terrains (which tend to have smaller permit areas). The overall cost impact will tend to be least in flat terrains characterized by large permit areas.
- 4) The legal, complaint, cost and density analyses of this study do not suggest a general across-the-board lowering of regulations below 1.0 particle velocity, in/sec. However, there are unique situations where policy and regulatory flexibility may be needed in this regard.

To the extent that blasting is an issue in specific locations this has been seen as resulting from a broad and complex spectrum of interacting factors among which are included:

- 1) The existence of an opportunity situation, in terms of the closeness and density of housing and communities - a situation that we did not find prevalent.
- 2) Situations where the quality of blasting practice fell below normal achievable standards - a situation that could be observed in a number of cases.
- 3) The existence of "fly-by-night" mines which are often the source of problems, poor practices and poor community relations; and which need to be better controlled.

- 4) The difficulties that small mines have in obtaining and utilizing best technologies and practices.

These conditions are further exasperated by the general weaknesses in managerial and control practices of the industry, but mitigated by a positive and supportive mining culture in many communities (a modus operendi).

Over and above these more general conditions there remain unique combinations of special conditions (geological, social, individual, etc.) which may lead to unusual consequences in actual or perceived blast induced impacts. These need to be recognized and dealt with, but should not become the basis of generalized regulations.

Finally, we have suggested that the non-perjorative and more neutral term of "cracking" be substituted for the term "damage" and that such cracking be then evaluated in terms of its cosmetic, load loss and repair implications.

These issues and their implications for action changes and for needed future research are elaborated in more detail below.

II. REGULATORY REQUIREMENTS FOR LEVELS OF GROUND VIBRATION

One of the major issues which the findings of this study must address is whether or not the current Federal regulation of 1.0 in/sec should be maintained or changed, either to a higher or lower level. Consideration must be given to the impact of vibration levels on both communities and mines, as well as to the variety and interaction of factors involved.

The findings of this study do not support a reduction in vibration levels below the current 1.0 in/sec. Several considerations support this conclusion:

- The cost analysis suggests a sharply rising cost curve for drilling and blasting at levels below 1.0 in/sec, though this does not appear to hold true for area stripping methods of large permit areas in flat terrains.*
- Relatedly, vibration requirements below 1.0 in/sec can be expected to have a disproportionately strong impact on small mines.
- Actual vibration levels tend to be less than regulatory requirements — i.e., mines tend to allow a margin of error in order to ensure compliance with regulatory requirements. Enforcement of the 1.0 in/sec requirement would, therefore, have the effect of generally creating a de facto standard in the range of 0.7 - 0.9 in/sec.
- The 1.0 in/sec standard is generally sufficient to prevent the really severe types of cracking impacts. Thus, any benefits which might be gained by a lower vibration level must be weighed in balance with costs to mines of lower vibration levels.
- Analysis suggests that at or below 1.0 in/sec, the level of community awareness and response to blasting as an issue is primarily dependent upon factors other than the specific vibration level.
- In several sites, regulatory personnel stated essentially the same conclusions we have stated here. Contrarily, none of the regulatory personnel suggested a need for lower vibration levels.

It is also to be noted that the findings of this study do not support consideration of raising regulatory requirements to a level above 1.0 in/sec. This level is well within current state-of-the-art capabilities,

* Cost increases are significant for individual blasts below 1.0 in/sec, regardless of size of permit area, but the overall average cost for a total permit area decreases as size of the permit area increases simply because blasts away from the permit boundaries (toward the interior of a permit area) become more distant from structures outside the permit area.

and the cost analysis suggests a minimal cost increase to mines from 2.0 to 1.0 in/sec. This minimal cost increase was also generally confirmed during field site interviews and observations.

Further, this study found that in response to the setting of regulatory standards at 1.0 in/sec, a significant number of mines have come to utilize more efficient and effective methodology to offset the cost impact of the regulation, while other mines had already been blasting at the 1.0 in/sec level. Additionally, community members and regulatory personnel at several sites suggested that the PL 95-87 has lessened blasting impact on community.*

It may be noted, of course, that future developments in state-of-the-art technology might permit further lowering of vibration levels (below 1.0 in/sec) with the corresponding cost increases noted in this study. Until such technological improvements are developed, however, cost increases can be anticipated below the 1.0 in/sec level.

* We note that PL 95-87 includes requirements other than 1.0 in/sec (e.g.: monitoring, pre-blast surveys). It is thus difficult to determine whether the i.p.s. regulation per se or the combination of requirements is predominant here. Additionally, analysis suggests that active enforcement per se is a significant factor in reducing blasting impacts.

III. ASSURING QUALITY OF BLASTING PRACTICE: A PORTFOLIO OF POLICY RESPONSES

It is a basic finding of this study that quality of blasting practice — the ability and willingness of mines to utilize state-of-the-art methodology to control vibration, dB and flyrock — is a critical factor for minimizing blasting impact on community. Thus, assuring quality of blasting practice needs to be a basic area of policy concern, with control of fly-by-night operations being a major dimension of the quality of blasting practice issue.

We believe that quality of blasting practice can best be assured by a portfolio of policy responses which are relevant to various aspects of the quality of blasting practice issue. Such a portfolio can be developed around three primary emphases: competency of drilling and blasting personnel; active enforcement of regulations; and local options for control.

A. Ensuring Competency of Mine Drilling and Blasting Personnel

To ensure that mines do in fact meet regulatory requirements on blasting practice, it is also necessary to ensure that mine drilling and blasting personnel have the technical knowledge and skill competencies necessary to meet regulatory requirements. Among the policy responses which might be relevant here would be:

- * Development of standards and certification processes for blasting personnel.
- * Development of training mechanisms for blasting personnel.
- * Provision of technical assistance to mines.
- * Development of linkages within the mining industry's infrastructure for the transfer of technology.

Several observations must be made here. First, these policy responses are obviously interrelated. For example, provision of technical assistance would be facilitated through development of linkages within the industry's infrastructure.

Second, there could be a variety of ways to implement these policy responses. For example, training or technical assistance could be provided (or supported) by governmental agencies (at either Federal, state and/or local levels), by units of the industry infrastructure (manufacturers, distributors and/or professional associations), and/or by local colleges or technical schools.

Third, where blasters lack competency in design or technology, training and/or technical assistance would be an appropriate policy response. However, in the case of fly-by-night firms (where lack of concern for blasting impacts is the issue), the enforcement of regulations would be the appropriate (indeed required) policy response.

Fourth, further information is needed in order to determine the most appropriate methods for implementing the above policy responses. Specifically, further information is needed regarding:

- * The extent of the need for these policy responses.

On the one hand, this study found instances where mines have already improved their blasting proficiency in response to PL 95-87. However, it was not possible within the scope of this study to determine the extensiveness or adequacy of this development.

- * The adequacy of current sources of training and technical assistance, and the adequacy of linkages between mines and sources.

Training and/or technical assistance is currently being provided through local college and technical school programs, consultants, distributors. However, the field research of this study indicates variation in both the quality of training or technical assistance being provided and the adequacy and extensiveness of linkage mechanisms.

- * The extent to which smaller mines might be affected by the costs involved in obtaining training or technical assistance.

B. Active Enforcement of Regulations

The findings of this study suggest that active enforcement of current blasting regulations can significantly reduce the level of blasting impact on community. Most directly, current regulations seem adequate to control the very severe types of blasting impacts in most cases -- assuming the regulations are enforced. Further, in the previous discussion of findings, sites were noted where regulatory personnel, mine personnel and community leaders stated that active enforcement of already existing state regulations had minimized blasting impacts on community.

A related observation needs to be made here. A number of interviewees in several sites suggested that enforcement of regulations (state and/or Federal) has been hampered by disaggregation of authority and responsibility across several state agencies and/or between Federal and state agencies. This suggests that careful consideration (and monitoring) needs to be given to the relative roles of and interaction between Federal and state agencies in relation to enforcement of regulations.

C. Options for Local Control

There are options that local communities can exercise for the control of blasting impacts. For example, county governments can exercise control through such mechanisms as bonding requirements and permit hearings which are open to the public.

A more informal mechanism noted in this study involves a modus operandi of direct mine-resident negotiation which permits residents to be compensated, in most instances, for blast-induced cracking. It is further

to be noted that this mechanism often permits resolution in favor of the resident in those cases where it would be difficult to determine factually whether or not blasting is the actual cause of cracking.

Several observations need to be made here. First, the use of such a mine-community modus operendi seems to perform two basic functions. The first function is to moderate (through reimbursement) the costs which citizens bear from blasting impacts. This may be seen as the basic function of a modus operendi. Secondly, however, the findings of this study suggest the hypothesis that this mechanism also serves as a communication feedback loop to mines which can lead to modification of blasting practice by mines, i.e., the modus operendi process appears also to serve a preventive function.

Second, development and maintenance of such a modus operendi obviously depends upon the goodwill and good faith on the part of both mines and communities. However, this study suggests that such a goodwill/good faith relationship is more likely to develop (though it may not) in small rather than large communities — a finding which is consistent with general sociological principles.

Third, analysis across field sites suggests that a modus operendi is most likely to be developed and maintained when the following constellation of factors is present: the presence of a mining culture within the community; stability among both mines and community residents; good quality of blasting practice by mines; mine participation in the community; and a non-metropolitan area.

Fourth, further research is needed into the nature and dynamics of such modus operendi. Some of the pertinent issues would be: the extent to which they serve to reduce the costs of blasting impacts to community; contrarily, the extent to which they provide inadequate compensation for blast induced cracking; the extent and causes of any current decline in the effectiveness and use of these modus operendi.

IV. IMPLICATIONS REGARDING THE SURFACE COAL MINING INDUSTRY

While it was not within the purview of this study to provide an in-depth analysis of the surface coal mining industry, a number of tentative findings did emerge.

- 1) Control of Fly-By-Night Firms — This study suggests that fly-by-night firms are a significant source of blasting (and other) impact on community. Their control would thus be an appropriate (and focused) area of policy response — quite probably in collaboration with local governmental agencies. Further study is needed to determine: the extent of the fly-by-night problem (as a general impact issue and not just with regard to blasting); possible difficulties in identifying, monitoring and controlling such firms (a factor suggested by several interviewees); and the nature of appropriate policy response(s).
- 2) Industry Infrastructure and the Transfer of Technology — The findings of this study suggest that the coal mining industry has a very loosely coupled, disaggregated infrastructure — but that nonetheless, the mine company/manufacturer/distributor relationship has the potential to be an important mechanism for the transfer of technology to mine companies. Consideration also needs to be given here to the issue of training. The Northwestern University Center for the Interdisciplinary Study of Science and Technology is currently studying one aspect of this issue under contract with the National Science Foundation.
- 3) Cost Accounting Procedures — Efforts to obtain cost information from mine companies for this study revealed that in many instances, company cost accounting procedures were inadequate for determining the real cost of a firm's drilling and blasting. In a number of instances, this appears to have masked methodological drilling/blasting cost inefficiencies and, thereby, hindered the acquisition and use of available drilling/blasting technology. There is a clear need for the development and dissemination of cost accounting practices suited to mining operations and the provision of training programs to assist mines (especially smaller mines) to utilize better cost accounting procedures. Further study is also recommended to provide a more detailed picture of: (a) the extent and distribution of such cost accounting inadequacies within the industry; and (b) appropriate policy responses (e.g.: OSM or Bureau of Mines technical assistance; governmental support for the development of relevant training programs by local colleges and/or by manufacturers or distributors).
- 4) Small Mines — There were a number of indications that small mines: (a) lack the capability (or the resources or contacts for developing the capability) to obtain and use state-of-the-art technology; and (b) are more significantly affected by blasting (and other) regulations. While these findings must be considered tentative, they were sufficiently pervasive in this study to suggest further study by the Bureau of Mines.

V. POLICY FLEXIBILITY/INTERACTIVENESS

Special combinations of conditions do arise which lead to unusual blast related consequences (Site No. 8 was such an example). To base general regulations on such relatively rare situations would place an unnecessary and costly burden on the industry, on the mining communities, and on the nation -- in terms of the availability and cost of coal. Again, there are differences in impact when blasting occurs in small mining communities and near large metropolitan areas. There are three general implications:

1. Regulations can not be rigidly based on single factor purely technical considerations, such as vibration levels at a given distance or location. Variations and the potential for variances based on demographic, geographic, geologic, social and other conditions need to be considered.
2. Regulations should not be designed to deal with problems occurring in special and "hot spot" situations. They should be based on considerations that would cover most, but not extreme cases. These should be dealt with as special variance cases, requiring special local regulations and/or special compensation agreements. OSM and/or Bureau of Mines may need to become more active in identifying the types of combinations of conditions that give rise to such hot spot potential situations - as guidance to mines, communities, local authorities and the courts.
3. The enforcement of regulations, the assistance provided to mines, and other such policy matters may need to vary with respect to type of mine. Small mines have different problems and needs from large mines. Fly-by-night mines need to be controlled differently from long-term stable mines. There needs to be flexibility and adaptiveness in the government policy process that can accommodate such variability.

Finally, it must be kept in mind that in some cases negative reactions to "blasting" may actually reflect a more generalized opposition to the mine(s) and to their overall operations. Because of regulations regarding blasting - this becomes the available form for opposition and perhaps claims. Again, it must be recognized that problems of this type will not cease by tightening up or more strongly enforcing blasting regulations. This would merely shift the manifestation of the problems to another area, or act as a suppressant rather than a solution. Response to such "blasting" complaints must be dealt with in a much more complete and sensitive manner, providing guidance to mines, communities and the courts as to the real combinations of problems that are at issue.

VI. CLASSIFYING STRUCTURAL IMPACTS

The review of damage classification systems revealed a lack of consistency and the use of vague criteria and connotative terminology. It is therefore recommended that:

- 1) the term "cracking" be used instead of the term "damage"
- 2) the severity of cracking be evaluated along three dimensions:
 - a) an aesthetic dimension (cosmetic cracking)
 - b) an engineering dimension (load loss)
 - c) an economic dimension (cost of repair for either cosmetic or load loss cracking).

Further, it is recommended that for court-of-law purposes, a legal definition for cracking and annoyance be prepared under the auspices of the American Bar Association, using the above dimensions.

VII. THE ROLE OF OSM

This study was conducted too soon after the establishment of OSM to make any determination of its role and impact. Thus, this area will await further study in a three to five year period after the establishment of OSM. However, the need for such a study is indirectly supported by two findings of this study: (a) evidence that state regulatory agencies have, in some cases, had a positive effect in reducing blasting impacts on communities; and (b) evidence that disaggregatedness of regulatory roles within a state has, in some cases, had the effect of hindering efforts to control the impacts of blasting on communities.

VIII. TECHNICAL CONSIDERATIONS REGARDING ANNOYANCE

The analysis of annoyance (Section One, Part Six) suggests the following considerations.

1) Relationship Between Air Blast Peak Over Pressure and C-Weighted Sound Level with Slow Meter Response

Measuring the true peak sound pressure of an air blast from a mine or quarry (or sonic boom) requires special instrumentation with extended low frequency response (down to 0.1 Hz). The current blast monitoring instrumentation used in the field cannot accurately measure the 1 Hz peak associated with an air blast. The proposed blasting limits from OSM further complicates the picture by permitting the use of measurement systems with four different frequency weighting characteristics. It is recommended that OSM adopt ANSI S1.4-1971 specifications for a precision sound level meter set for C-weighting slow meter response, CSEL, or alternative systems that record air pressures at frequencies associated with house "rattle". The cost of the precision sound level meter meeting the ANSI standard could be greatly reduced if the instrument were required to meet the precision sound level meter standard over the frequency range from 10 Hz to 1,000 Hz. To permit

blast noise measurements for monitoring or enforcement with a measuring system with a low frequency roll-off of 6 Hz, 2 Hz or some other frequency, without requiring the measuring instrumentation to meet a rigorous performance specification is likely to lead to chaos. It is not difficult to envision two non-standard instruments from different manufacturers with identical low frequency cut-off, giving measured results 20 dB apart.

2) Recording of Time Histories of Blast Events

ANSI 1.4-1971 specifies the frequency response of the C-weighted network for a standard precision sound level meter over a wide frequency range starting at 10 Hz at the low end. It is the only standardized frequency weighting network that correlates fairly well the measured blast noise and resulting wall velocity in typical dwellings. Further research studies on the response of structures to blast noise should certainly consider more than the C-weighted slow response of a sound level meter for measuring the blast noise. For any additional studies, it is recommended that the sound measuring system tape record the entire blast event. The entire recording and reproduction system, including the microphone, should have a uniform frequency response extending from 0.1 Hz to approximately 500 Hz. Air blasts recorded in this manner will permit detailed analysis in both the time domain and frequency domain.

3) Some Areas for Further Research

The analysis in this study of annoyance reveals a number of areas where current data is inadequate and which therefore require further research. Among these are the following:

- a) The effect of local/abnormal weather conditions on long delayed sound reflections and blowouts (air blasts over large distances).
- b) The relation between number of booms or blasts per day (assuming constant energy level per boom) to levels of annoyance.

This study suggests that annoyance is equated more with energy level than with the number of booms per day -- i.e., one "big bang" causes more annoyance than several "little bangs" having the same cumulative total energy. However, little is yet known whether (and if so under what conditions and at what point) the actual number of booms (assuming constant energy level) becomes a factor in increasing annoyance levels.

- c) The relation between the percent of people very annoyed and the number of people who will lodge a complaint.

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