The Effects of Strip Mine Blasting On Residential Structures Ayrshire Mine Warrick and Vanderburgh Counties, Indiana

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Purpose

Investigation of numerous complaints regarding structural damage to residences in the vicinity of the Ayrshire Mine, Warrick County, Indiana (Figure #1), prompted a twelve-month study into the nature and cause (or causes) of this widespread and severe damage. Data were collected from November 1976 through May 1977. The cumulative effects of repeated strip mine blasting were thought to be the most probable cause of this damage, and a study was designed to confirm or disapprove this belief.

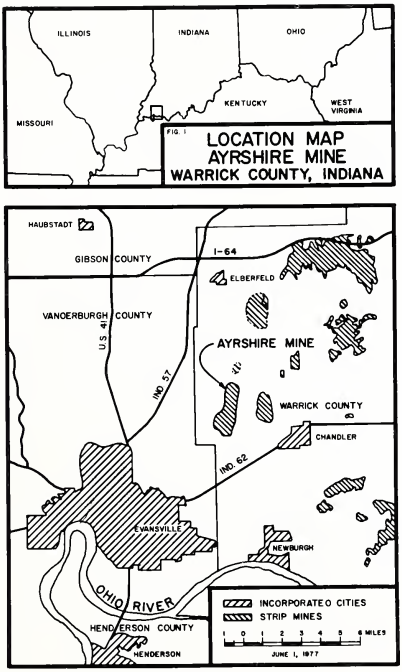

FIGURE 1.

It is known that shock waves from a blast radiate outward in all directions from the source, and that the force decreases with an increase in distance from the blast. In a homogeneous medium shock waves radiate from a blast source in a spherical front. Therefore, distance from the blast area should be the prime factor influencing structural failure.

If strip mine blasting were the dominant cause for this widespread residential damage a similar halo pattern of concentric destruction radiating outward from the blast source should be apparent within the area studied. Damage should decrease with an increase in distance from the mine face where blasting occurs. This study was designed to test this hypothesis.

Area Studied

The area studied consists of rolling farm land and low-lying bottom land situated in western Warrick and eastern Vanderburgh Counties of Southwestern Indiana (Figure 1). Much of the western portion of the area is situated on an ancient lake bed that is now filled with 80-120 feed of unconsolidated alluvium. Ths fill rests of Paleozoic beds of shale, sandstone and siltstone.

Strip mine operations at the Ayrshire Mine involve blasting and removal of 70-90 feet of siltstone, sandstone, shale and limestone that overlie the upper and lower Millersburg coals of Pennsylvanian Age. Blasting occurs within one mile of the lake bed alluvium.

Approximately 1300 homes are located within the survey area. Most residences are one-story, bungalow-type homes containing 1000-1500 square feet. Most have basements (62%), while construction type is divided between frame (36%), brick-block (43%) and combination (21%). The homes examined range from two years of age to log homes more than 100 years old.

Method of Study

A Home Damage Report form was devised to indicate location and type of damage, age of house, construction type, blast frequency, etc. (Figure 2). Mobile homes were not considered to be anchored to the ground firmly enough to register the strains applied to a standard home during blasting operations and were not included in this survey. Mobile homes were also excluded from a similar study of blasting damage conducted for the Atomic Energy Commission in 1973.

The strip mine blasting area (high wall), bordering trench and mined-out area associated with the Ayrshire Mining operation, were located and plotted on a U.S. Geological Survey topographic map through ground investigation and overflight. Survey grid lines were then established along county roads indicated on a topographic map of the area.

Concerned neighbors, students and parishioners of St. John's Catholic church formed survey teams of one or two persons each. These investigators were instructed in map reading and in completing Home Damage Reports. Each survey team was given a topographic map of the area on which they located each home with a number that matched the corresponding Home Damage Report number. Surveyors were instructed to take random samples located approximately one-half mile apart along established grid lines. Clustering of data in some areas was unavoidable because they were the only data available. Many homes close to the mine were owned by Amax Coal Company, or had been abandoned by the previous owners, resulting in an unavoidable scarcity of data within one mile of the Ayrshire Mine. A total of 169 homes were surveyed,

FIGURE 2

Date________________________

Report No.________________

HOME DAMAGE REPORT

1. Home Owner____ Age of Home____________
2. Address ____ Phone ________________
3. Distance from Ayrshire Mine In Feet__________________
4. Number of Rooms (Exclusive of Basement) ______________
5. Basement ( ) Yes; ( ) No.
6. Water Well ( ) Yes; ( ) No.
7. Construction: ( ) Frame ( ) Block ( ) Brick ( ) Combination
8. Basement:
   A. Square Footage________________
   B. Number of Hairline Cracks________________
   C. Number of Cracks Larger than Hairline________________
   D. Number of Cracks Longer than 5 ft.________________
   E. Number of Horizontal Cracks Longer than 5 ft.________________
   F. Total of Number of Cracks________________
9. Living Area Above Ground:
   A. Number of Floors________________
   B. Square Footage________________
   C. Number of Hairline Cracks________________
   D. Number of Cracks Larger Than Hairline________________
   E. Number of Crakcs Longer than 5 ft.________________
   F. Number of Horizontal Cracks Longer than 5 ft.________________
   G. Number of Horizontal Cracks at Junction of Wall and Ceiling________________
   H. Total Number of Cracks________________

10. According to the homeowner, have cracks increased in width, length or number since the opening of the Ayrshire Mine?

Width: ( ) Yes ( ) No
Length: ( ) Yes ( ) No
Number: ( ) Yes ( ) No

11. Record any other damage that has occurred since blasting at the Ayrshire Mine commenced. (Damaged water wells or cisterns, porches, stoops, chimneys that have cracked or separated from the house; doors or windows that no longer fit, abundant chipped bricks, etc.)

____

____

12. How many times a week is your home shaken by blasting?________________

13. Does blasting occur at night? ( ) Yes; ( ) No.
on Sunday? ( ) Yes; ( ) No.

____
(Signed) Examiner)

____
(Signed) Homeowner

in an area including an estimated 1300 homes which were indicated on the most recent topographic maps of the area. Of these, six were discarded because the home owner or resident did not attest the survey form with his (or her) signature. Sites unusually close to each other were occasionally combined as representative of that particular area. (Points 82 and 147 represent two and five homes respectively). Lack of funds, time and personnel resulted in a more concentrated random sample of data points within a four-mile belt trending approximately north-south and parallel with the mine face, which is located to the east of sampled area. Data were cross-checked for accuracy and plotted on a topographic map of the area as survey teams returned from the field.

The data were divided into the following categories and color coded on a topographic base map according to the nautre and extent of damage reported.

a. Blasts not felt—no damage reported (yellow)
b. Blasts felt—no damage reported (green)
c. Blasts felt—damage reported
   1. Sub-surface damage
      a. Damage to water wells, septic tanks and cisterns (blue)
      b. Damage to basement floors, basement walls and foundations (red)
   2. Surface damage
      a. Damage to windows, doors, porches, patios and garage floors (orange)
      b. Damage to living area walls, fireplaces, chimneys and brick or stone veneer (black)

One-mile zones were then drawn around the blasting area measuring from the high wall shown in Figure 3.

Percentages of homes reporting each type damage reported in Figure 3 were calculated in each one-mile blast ring. The blast ring effect that is indicated resulted from these calculations.

These are as follows:

Zone I	12 of 12 homes surveyed reported damage	100%
Zone II	38 of 42 homes surveyed reported damage	91%
Zone III	38 of 42 homes surveyed reported damage	64%
Zone IV	14 of 35 homes surveyed reported damage	40%
Zone V	9 of 19 homes surveyed reported damage	47%
Zone VI	11 of 15 homes surveyed reported damage	73%

Observations of home characteristics were assembled from the surveys located in each zone and summarized in Table 1.

TABLE 1. *Summary—Home Damage Survey*

1. *Age of Structure*

5 Years Old:

Zone I = 2/12 (17%); II = 0/42 (0%); III = 5/38 (13%); IV = 2/35 (6%); V = 0/19 (0%); VI = 2/15 (13%).

5-10 Years Old:

Zone I = 2/12 (17%); II = 6/42 (14%); III = 5/38 (13%); IV = 5/35 (14%); V = 2/19 (10%); VI = 1/15 (7%).

11-20 Years Old:

Zone I = 1/12 (8%); II = 8/42 (19%); III = 7/38 (19%); IV = 8/35 (23%); V = 10/19 (53%); VI = 4/15 (27%).

TABLE 1. *Summary—Home Damage Survey* (continued)

21-40 Years Old:
Zone I = 4/12 (33%); II = 21/42 (50%); III = 13/38 (34%); IV = 9/35 (26%); V = 6/19 (32%); VI = 6/15 (40%).

Over 40 Years Old:
Zone I = 3/12 (25%); II = 7/42 (17%); III = 8/38 (21%); IV = 11/35 (31%); V = 1/19 (5%); VI = 2/15 (13%).

2. *Construction*
More Than One Story Above Ground Level:
Zone I = 3/12 (25%); II = 8/41 (20%); III = 9/39 (23%); IV = 10/35 (29%); V = 5/19 (26%); VI = 6/15 (40%).

Homes With Basements:
Zone I = 7/12 (58%); II = 32/42 (76%); III = 13/39 (33%); IV = 24/35 (69%); V = 11/19 (58%); VI = 12/15 (80%).

Frame Construction:
Zone I = 7/12 (58%); II = 15/42 (36%); III = 19/38 (50%); IV = 11/35 (31%); V = 4/19 (21%); VI = 3/15 (20%).

Brick-Block-Stone Construction:
Zone I = 5/12 (42%); II = 19/42 (45%); III = 13/38 (34%); IV = 17/35 (49%); V = 10/19 (53%); VI = 5/15 (33%).

Combination Construction:
Zone I = 0/12 (0%); II = 8/42 (19%); III = 6/38 (16%); IV = 7/35 (20%); V = 5/19 (26%); VI = 7/15 (47%).

3. *Homes Indicating Surface or Subsurface Structural Failure*
Zone I = 12/12 (100%); II = 38/42 (91%); III = 25/39 (64%); IV = 14/35 (40%); V = 9/19 (47%); VI = 11/15 (73%).

4. *Subsurface Failure—Basement Cracked*
Basement Cracked:
Zone I = 3/7 (43%); II = 26/32 (81%); III = 3/13 (25%); IV = 7/24 (29%); V = 3/11 (37%); VI = 5/12 (42%).

More Than Two Cracks Larger Than Hairline:
Zone I = 1/5 (20%); II = 15/31 (49%); III = 2/13 (15%); IV = 1/24 (4%); V = 0/10 (0%); VI = 0/11 (0%).

More Than Two Cracks Longer Than Five Feet:
Zone I = 1/5 (20%); II = 7/31 (23%); III = 0/13 (0%); IV = 1/24 (4%); V = 0/10 (0%); VI = 0/11 (0%).

More Than Two Cracks:
Zone I = 1/5 (20%); II = 21/31 (68%); III = 2/13 (15%); IV = 4/24 (17%); V = 0/10 (0%); VI = 4/11 (36%).

5. *Surface Failure—Living Area Above Ground Level Cracked*
Living Area Above Ground Cracked:
Zone I = 11/12 (92%); II = 32/42 (76%); III = 20/39 (51%); IV = 9/35 (26%); V = 6/19 (32%); VI = 10/15 (67%).

More Than Two Cracks Larger Than Hairline:
Zone I = 5/12 (42%); II = 15/42 (36%); III = 8/39 (20%); IV = 4/35 (11%); V = 0/19 (0%); VI = 0/15 (0%).

More Than Two Cracks Longer Than Three Feet:
Zone I = 2/12 (17%); II = 14/42 (33%); III = 7/39 (18%); IV = 3/35 (9%); V = 0/19 (0%); VI = 0/15 (0%).

More Than Two Cracks:
Zone I = 10/12 (83%); II = 26/42 (62%); III = 16/39 (41%); IV = 6/35 (17%); V = 3/19 (16%); VI = 6/15 (40%).

More Than Four Cracks:
Zone I = 8/12 (67%); II = 21/42 (50%); III = 14/39 (36%); IV = 6/35 (17%); V = 2/19 (10%); VI = 4/15 (27%).

6. *Homes Reporting Increase in Crack Width, Length or Number Since Opening of Ayrshire Mine*
Zone I = 11/12 (92%); II = 32/42 (77%); III = 18/39 (46%); IV = 9/35 (26%); V = 3/19 (16%); VI = 3/15 (20%).

7. *Blast Frequency*
Home Shaken Less Than Five Times/Week by Blasting:
Zone I = 3/10 (30%); II = 11/38 (29%); III = 18/34 (53%); IV = 19/32 (59%); V = 14/18 (78%); VI = 13/14 (92%).

Home Shaken Five To Ten Times/Week By Blasting:
Zone I = 2/10 (20%); II = 11/38 (29%); III = 10/34 (29%); IV = 9/32 (28%); V = 2/18 (11%); VI = 1/14 (7%).

Home Shaken More Than Ten Times/Week By Blasting:
Zone I = 5/10 (50%); II = 16/38 (42%); III = 6/34 (18%); IV = 4/32 (13%); V = 2/18 (11%); VI = 0/14 (0%).

Home Reporting Sunday Blasting:
Zone I = 3/9 (33%); II = 13/40 (33%); III = 6/30 (20%); IV = 3/26 (12%); V = 2/7 (39%); VI = 1/7 (14%).

Home Reporting Night Blasting:
Zone I = 5/10 (50%); II = 23/41 (56%); III = 20/39 (51%); IV = 9/32 (28%); V = 8/14 (57%); VI = 2/8 (25%).

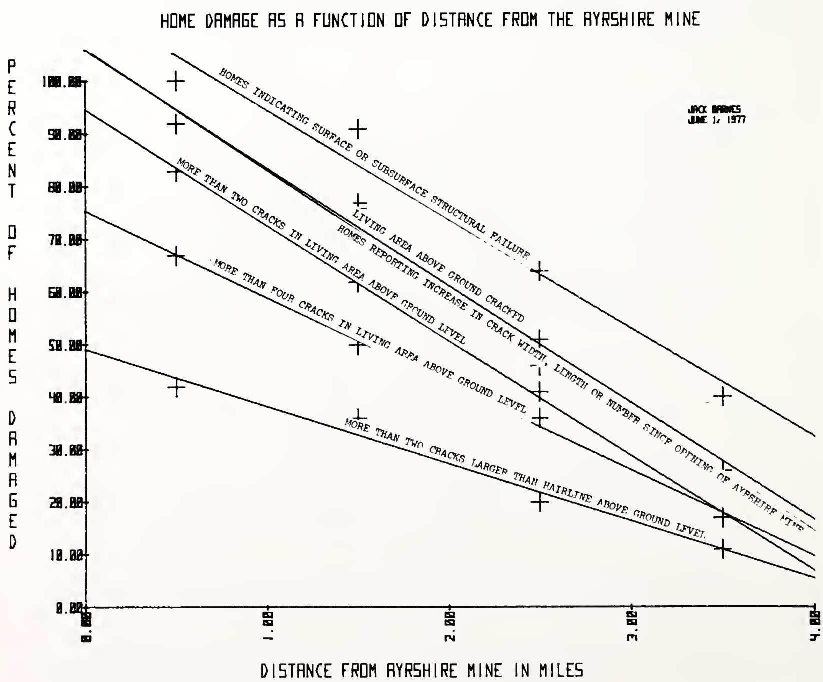

FIGURE 2.

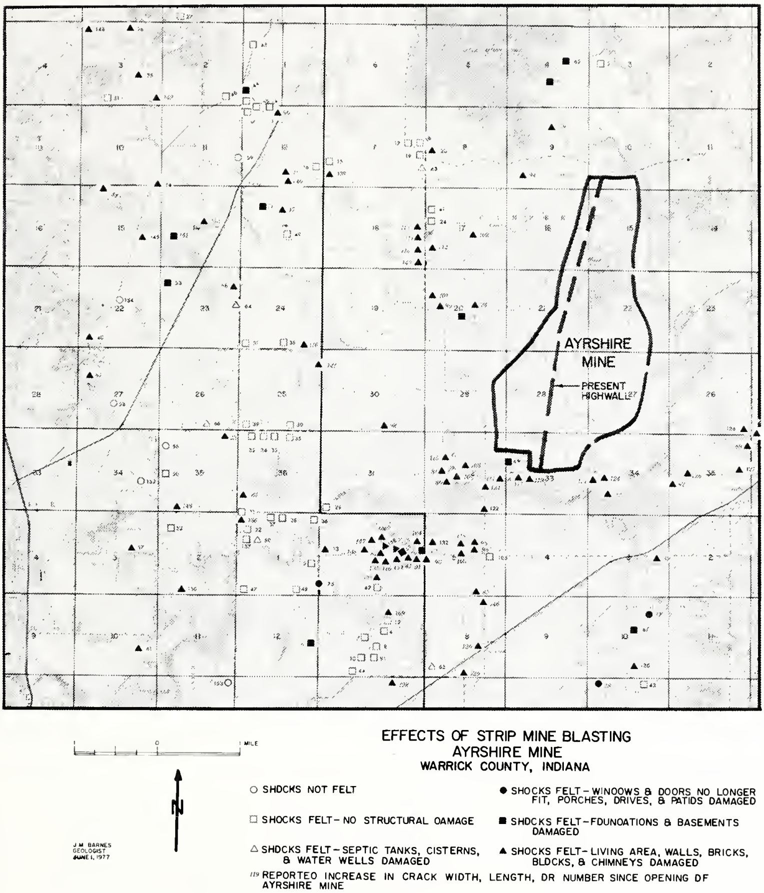

FIGURE 3.

The data indicated a linear drop in damage effects with an increase in distance from the mine face. These data were illustrated graphically in Figure 4.

Data concerning the nature, distribution and thickness of alluvium were obtained from records of oil, coal and water tests in the area. This informatin was obtained from The Indiana Geological Survey, Bloomington, Indiana; The U.S. Geological Survey, Indianapolis, Indiana; Indiana State University Evansville, Evansville, Indiana; and The Indiana Water Resources Division of The Department of Conservation, Indianapolis, Indiana. An isopachous map of unconsolidated fill was constructed from data contained in approximately 130 wells and illustrated in Figure 5.

A geologic cross section of the surface geology within the area studied was prepared to illustrate the effects of shock wave propagation in alluvium (Figure 6).

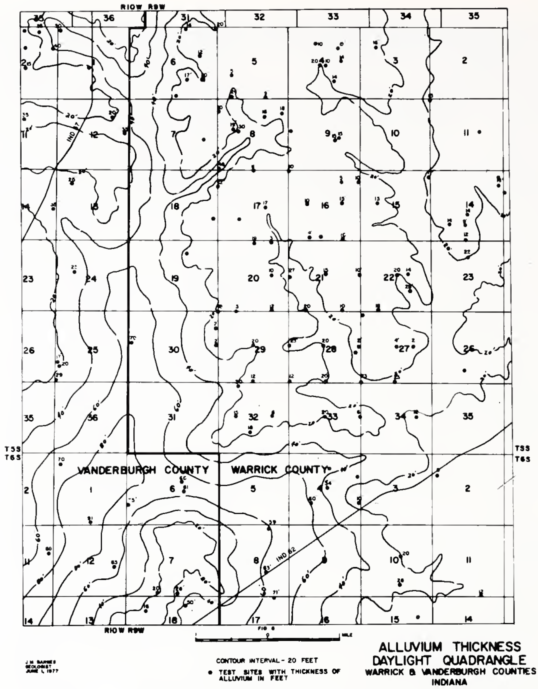

FIGURE 4.

A profile of abnormal residential structure failure was constructed along the geologic cross section A-A' to further illustrate the effects of repeated blasting near thick water-soaked alluvium. These effects are illustrated in Figure 7.

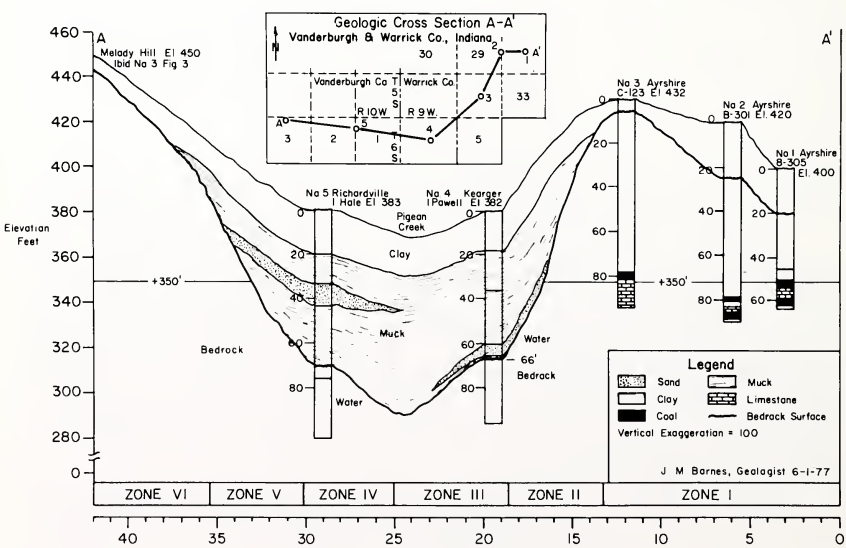

FIGURE 5.

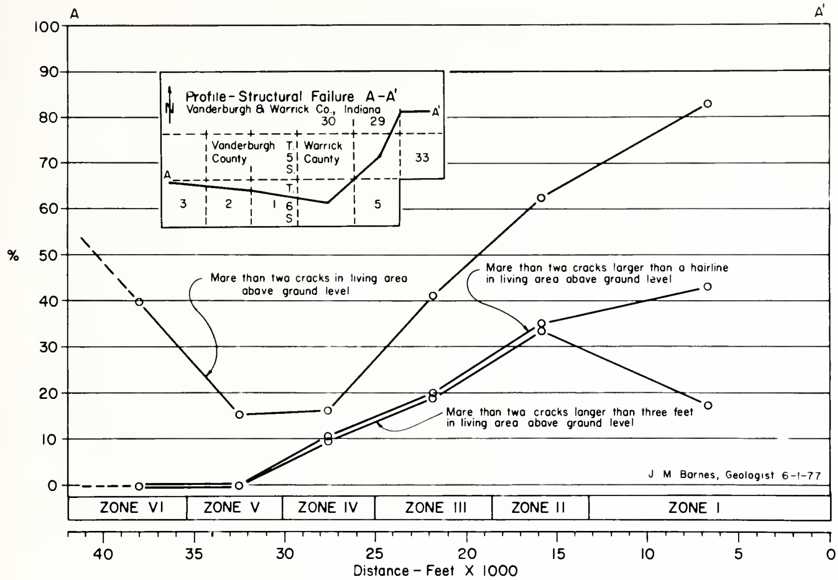

FIGURE 6.

Conclusions

This study was designed to prove or disprove the hypothesis that repeated strip mine blasting at the Ayrshire Mine was responsible for the severe and widespread structural failure observed in residences near the mine. The results of the study prove the hypothesis. The dominant factor in residential structural failure within three miles of the Ayrshire Mine is repeated blasting during stripping operations at this mine. Within four miles of the blasting area residential structural failure decreases linearly with distance from the mine face (R^2 = .96 to .99, depending on criteria measured) (Figure 4). Other possible causes of structural failure such as freezing and thawing, age of house, construction type, soil type, etc. are negligible, when compared with the overwhelming effects of repeated strip mine blasting. Age has been largely eliminated as a factor by the criteria established for abnormal structural failure. Other factors in residential structural failure do not occur as a function of distance from the mine face. Only the blast force occurs as a function of distance from the mine face. The determination of whether this structural failure is due to 1) structural fatigue, 2) amplification or focusing of shock wave intensity in alluvium, and/or 3) subsidence due to repeated vibration was not within the scope of this study. All of these possible explanations require additional investigation. Nevertheless, the data gathered and anlayzed indicates that blasting at the Ayrshire Mine is the cause of the abnormal residential structural failure observed within three miles of the mine face.

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