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EFFECTS OF SURFACE MINE BLASTING ON UNDERGROUND MINE OPENINGS

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ABSTRACT

Field studies at an underground mine site were conducted to evaluate and monitor blast-induced vibrations on an underground coal mine roof. The vibration data were evaluated so that a suitable damage criteria or guidelines from which a safe operating distance between surface blasting and underground mine operations can be established.

Data obtained from the field studies were synthesized and evaluated for frequency content and duration characteristics. Computerized blast response spectra were produced from the field vibration recordings which can be used for actual field application purposes. The finite element program entitled DYNON (Dynamic Non-linear Analyses) combined with energy density spectra have been developed for simulating he existing field configuration at the mine site.

INTRODUCTION

Blast-induced ground vibrations from surface coal mine blasting may have a detrimental effect on nearby underground coal mine openings. The effects of these round vibrations generated from surface mining also have been of increasing public concern. Numerous studies on measurement and analysis of ground vibrations, and heir effects on structures and people were conducted by the U. S. Bureau of Mines.

Under the Surface Mining Control and Reclamation Act of 1977, the Office of Surface Mining has been implementing regulations governing peak particle velocity and airblast. Ground vibration in terms of peak particle velocity is limited to a 1 inch/second criterion. Mine operators are either monitoring the ground vibration for each shot from surface strip mines, using a scaled distance factor of 60, or undertaking seismograph measurements to prove otherwise that a smaller scaled distance can be used.

A wide range of instrumentation and support services are available on the market today. Most offer many choices to the operator for choosing a type of monitoring system. In selecting the correct instrumentation, a decision must be made as to the method of data collection and the type of information desired. Vibration data can be collected by recording the peak values or by capturing the entire waveform from a seismograph. The latter provides information about the duration and frequency content of the vibrations. The external force or pressure exerted by blasting and the induced stress created in a mine roof can be measured by strain gages or transducers.

DESCRIPTION OF THE TEST SITE AND MINING OPERATIONS

It is well known that geologic effects cause a difference in wave propagation. If the rocks at the site are essentially horizontal and stratified and consist chiefly of massive rock units with horizontal isotropy and uniform cover, little difference in wave propagation would be expected with direction. Conversely, if there are structural discontinuities such as jointing, folding, faulting anisotropy, or any other type of lineation, such as a mineralogical and/or grain oriented fabric, propagation may differ with direction.

Investigations have indicated that the thickness of soil and depth and degree of weathering have a direct effect on the amplitude and frequency or displacement recordings. Also, the intensity of vibration in loose soil and weathered overburden material is greater than in hard, unweathered bedrock media. For equal explosive charges and distances, gages installed on rock outcrops indicate lower amplitudes and higher frequencies than gages installed on the overburden. Because soil and overburden rock thicknesses vary from mine to mine and within some mines, brief, simple tests were conducted to determine whether or not similar effects were present in the particle velocity recordings.

Physiography and Geology

This research was done at the Shannon Mine of the Black Diamond Coal Company in the Appalachian Ridge and Valley physiographic province in east-central Alabama, Jefferson County. The mine is approximately four miles northwest of Abernant, Tuscaloosa County, and the mine portal is in the SW\, Section 3, T20, ROW, as shown in Figure 1. The mined area comprises approximately 180 acres underlying parts of Sections 3 and 10 of T20S, ROW.

The terrain is composed of hills and vales of low to moderate relief attaining a maximum elevation of 625 feet above mean sea level (msl) and a minimum relief of 480 feet above msl.

The surface drainage pattern is dendritic and consists chiefly of several small intermittent streams that flow in a northerly direction on the northwestern side of the property and several small intermittent streams which flow in a southerly direction on the southeastern side of the property. A series of northeasterly trending small strip mine lakes and strip mine spoil banks border the northwestern property boundary and an old strip mine lake cuts across the southwestern corner of the property.

The Shannon Mine and adjacent surface and underground mines occur in the extreme southwestern part of the Blue Creek Basin of the Warrior Coal Field of Alabama. Figure 2 is a plan view of the site showing a part of the underground mine.

The basin is an asymmetrical syncline that has a northeasterly trending axial trace and plunges to the northeast. The Shannon' Mine occurs at the southwestern extremity of the syncline close to the structural point of termination. The strata along the northwestern flank of the major structure has a relatively shallow dip to the southwest, which averages about 17°SW. Along the southeastern flank, the strata dip is much steeper, dipping as much as 80°NW.

The Blue Creek Basin is underlain by an alternating sequence of shale, sandstone, conglomerate, and coal seams of the Pottsville Formation of Pennsylvanian age. The rock units vary in grain size, color, and thickness. The lithologies range from mudstones and siltstones to sandstones and occasional pebble conglomerates. The thickness of different rock units range from laminae to thin-bedded to thick-bedded units that are mere partings of fractions of an inch in thickness for shales and shaly sandstones to sandstone units that are as much as 20 feet in thickness. The thicker sandstone units are well cemented and extremely tough and tenacious.

The coalbeds underlying the area are those represented by the Mary Lee group. The coalbeds presently being mined in the area from the oldest to youngest are the Jagger, Blue Creek, and Newcastle, with the Blue Creek being the most important. The basin is only about one mile wide at the mining site and the depth of cover ranges from 0 at the outcrop to about 500 feet at the bottom of the Shannon slope. The Blue Creek coalbed ranges from about 6 feet to 12 feet in thickness.

Faulting is common throughout the basin and the faults cut across the basin in oblique angles chiefly as normal faults with displacements ranging from only a few inches to as much as 100 feet. There are probably more faults that are not visible in the surface and subsurface. Movement parallel to and along bedding planes occurred during the folding process and evidence of this can be readily observed on some of the exposed rock surfaces. Jointing is common and the density and frequency varies according to local structural irregularities. The coal is general ly well cleated with butt and face cleats oriented in a northwesterly and northeasterly direction.

The Shannon Mine is a slope mine and the incline has an average slope of 10 degrees opened on the Blue Creek coal seam. The distance down the slope from the portal to the bottom is about 1800 feet.

Electric logs were run in a borehole at the site to substantiate the interpretation of the drilling log and provide additional subsurface data. The borehole was drilled 40 feet southeast of the survey control point and 342 feet deep penetrating a pillar in the Blue Creek coal seam and down to the underlying Jagger coal seam. Core samples were collected and selected samples of the core were tested in the laboratory for various physical strengths and properties. These data were compared with the geophysical logs for verification and correlation. Four electric logs were obtained from the run, including: (1) coal Ethology log; (2) seam thickness log; (3) coal quality log; and (4) multi-channel sonic log.

SITE PREPARATION AND BLASTING SEQUENCE

Based on information from an earlier blasting sequence, the site for the final blasting sequence was prepared by drilling one 4 inch-diameter borehole that was cased from the surface for about twenty feet with PVC. The hole penetrated the mine roof at 280 feet below the surface and left open-ended. A two-way mine telephone was installed and two vibration sensors were lowered into the hole and set at two different depths (Fig. 3).

A series of 6 1/2-inch diameter blast holes were then drilled in a cross pattern over the instrumented intersection in the mine. The array of holes is shown in Figure 4. The firing sequence, charge weights, depth of hole and stemming are given in Table 1.

The data obtained from each firing sequence was recorded by the instruments and these data were processed to provide the vibration responses for the study.

INSTRUMENTATION AND VIBRATION MEASUREMENT

A schematic diagram indicating the instrumentation and their respective location is shown in Figure 5. A portable Sprengnether engineering seismograph, model VS-1200 with three-component S-1400 seismometer is shown in Figure 6. Seismometers for recording underground vibrations were installed on the roof and floor of the mine. From the standpoint of potential damage to the mine, roof vibration levels were the critical parameter to be monitored. The seismometers were attached to the roof at three locations in the underground mine. Holes were drilled in the roof and 1/2-inch diameter by 4-foot long roof bolts were used to secure the transducer base plates (Figure 7). A VS-1600 seismograph designed for automatic and unattached field recording was placed on the mine floor (Fig. 8). Additional measurements were made by lowering two vibration sensors into a 4-inch diameter vertical borehole, one sensor model L-10-3D-SWC, Mark Engineering Borehole Seismometer (Fig. 3) was installed at a depth of 160 feet and at 60 feet a model 1462, Bison Instruments, Inc. sensor was installed (Fig. 9). This was to monitor vibration attenuation versus depth and to establish propagation relationship.

The responses were recorded in the peak particle velocity mode. The response traces are produced by the seismograph in terms of transversal, vertical, and radial direction of measurement. One of the traces is normally reserved for event making or air blast monitoring. A tube mounted strain gage as shown in Figure 10 was specifically designed and fabricated for the measurement of pressures in the coal pillar and installed at three different locations of 2 and 4 feet horizontally within the pillar. These were coupled and connected with strain indicators and recording modules of the VS-1200 seismographs. This is shown in Figure 11. The responses were recorded on the event marking trace as shown in Figure 12 as well as recording the peak particle velocity from one of the three seismometers installed on the coal mine roof. Three seismometers installed on the roof to record the ground vibrations were connected with three tube-mounted stress detectors that recorded the strain changes in terms of a dynamic stress. Figure 13 shows the installation of the tube mounted stress detector in the pillar and Figure 14 shows the instrument set-up for this part of the monitoring program.

DATA REDUCTION AND PROCESSING

The vibration data from the field responses were processed for the following purposes:

Maximum Response Spectrum Analysis
Fast Fourier Transform Analysis
Energy Spectral Density Analysis
Statistical Analysis for Scaled Distance Curve

The majority of the work involved with reduction and processing of data were done by a Hewlett-Packard HP-86 computer system with two flexible disc drives, a graphics plotter, a printer, and a digitizer. In order to correlate the results, a UNIVAC 1100 digital computer along with a TEKTRONIX 4050 graphic system were used for digitizing the seismograms, the drawing of the response spectrum and other graphs, and calculating the Fourier transforms.

Because the actual vibrations produced by surface blasting are similar in many respects to those produced by earthquakes, their response spectra are also quite similar, especially when reduced to simplified spectral envelopes that are useful for application purposes. A computerized blast response spectrum is shown in Figure 15. This is a typical spectrum, however, similar spectra were plotted from blast vibration recordings. It should be noted that blast shock spectra are sensitive to and must reflect the characteristics of the responding media, including particularly the amount of damping and/or the amount of inelastic deformation that might exist. Figure 16 through 19 show some sample outputs of fast Fourier transform in terms of velocity, acceleration, displacement, and energy density.

Whenever a safety level of ground vibrations from blasting is considered it is necessary to predict the vibration levels for a given blasting operation. This involves several parameters such as the distance from shot to the monitoring station, charge weight, and geological conditions at the site. It is reasonable to expect, however, the vibration level will be raised with increasing charge size and diminish with increasing distance from the blast. A generally accepted form associated with these parameters is as follows:

$$V = H\left(\frac{D}{W^{\alpha}}\right)^{\beta}$$

Where V is the peak particle velocity, W the charge weight, D the slant distance, and H, α and β are constants in terms of a given site or shooting procedure. These constants can be determined by linear regression analysis. Three sets of data fro the blasting sequence are grouped as surface, underground roof, and underground floor.

COMPUTER SIMULATION PROGRAM

The finite element program entitled DYNON (dynamic nonlinear analysis) has also been developed for simulating the existing field configuration. The Univac 1100/61 Computer system was used for the purpose of compiling the Fortran codes. Rectangular-shaped elements were incorporated into a finite element mesh for this analysis (Fig. 20). The mesh area was discritized into 181 elements with 210 joints. The underground opening is shaded on the mesh and is not considered an element. The purpose of the program is to enable one to evaluate the stresses around the underground opening (mesh) element, the contiguous elements 55, 68, and 69.

OBSERVATIONS AND CONCLUSIONS

The types of vibration recording instruments recommended are influenced by the frequencies generated by the blasting. Usually the observed frequencies ranged from less than 2 up to 150 Hertz for surface blasting. The velocity seismographs used in this study had a flat response of frequency ranges from 2 to 200 Hertz and would be adequate for most blasts monitored.

Waveforms of the recordings of all three ground vibration components generated by a blast are recommended for the peak amplitude measurements, however, frequency may vary among three components of motion; vertical, radial, and transverse. Peak or vector sum readings are adequate if only amplitude levels are desired. Empirically, the largest component of ground motion is usually the radial component at the surface and the vertical component in the subsurface.

The effects of blasting are significantly affected by the site geology both at the surface and in the subsurface. A thorough knowledge of the geology particular! the rock type, stratigraphic sequence, and structural conditions are essential. The hydrological conditions are also of prime concern. All of these parameters affect the type of shock or seismic wave generated and propagated within the media.

It was observed that the value of the vertical components of vibration data were relatively higher than that of the other components. This implies that in evaluating the effects on the underground openings caused by surface blasting, the vertical direction of vibration is the most important one to be considered.

The statistical analysis indicated that using the square root scaling provided a better result for the surface measurements and the underground measurements are best grouped by using cube root scaling.

The vibration curves using the Fourier transform approach showed that the frequency of the maximum amplitude remained as a constant for blasting, even though the responses were recorded from different locations. Therefore, a safety level of blasting could be determined by fast Fourier transform using the maximum amplitude and the frequency. Vibration levels measured on the mine floor were generally lower than those measured at the mine roof. The Fourier transform can be a powerful tool to study the safety criterion utilizing various frequencies. The vibrations containing higher amplitudes at a certain frequency range may generate damage to the underground mine openings.

The research indicated the adapability and usability of computer simulation to measure stresses imparted to an underground mine roof from blasting on the surface. In particular, a finite element analysis approach seems to provide a path to folio in similar studies of this kind. Certainly refinements in the techniques and procedures performed in conducting this work can be undertaken by other investigators interested in research related to blasting effects on underground mine roofs.

This study, as others indicated in the past, ascertained that data gained at a particular mine are limited to a site selective basis regardless of how many parameters can be produced in the simulation model. The stratigraphic succession of overlying rock units and the localized structural disruptions at each mine and the lithologic changes encountered in the vertical as well as horizontal sequences over relatively short distances, are too numerous and frequent to correlate from one coal basin to another with any degree of confidence. Nevertheless, the instrumentation and procedures for collection, analysis of the field data, and the computer programs utilized in this study indicate that these techniques are useful in analyzing the effects of surface blasting on underground mine roofs.

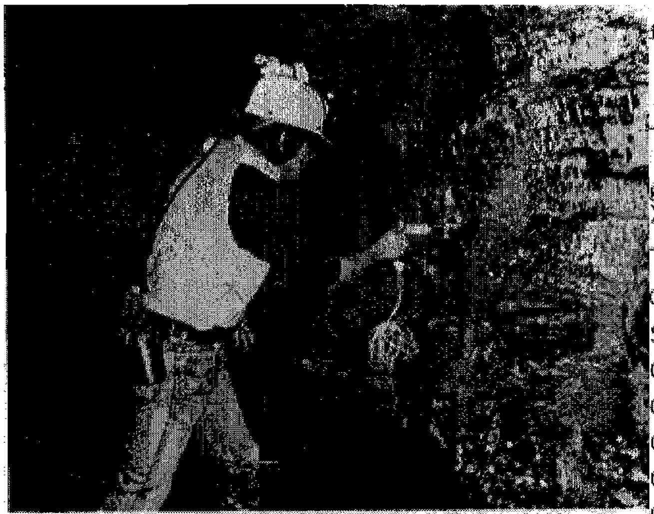
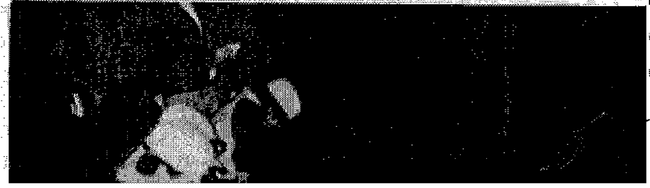


FIGURE 13



ing Sequence

of g Hole)	Stemming Depth (ft)
0	31.5
5	22.0
0	11.5
0	18.0
0	16.0
0	19.0
0	33.0
0	18.0
0	28.0
0	15.0
0	28.0
0	22.0
0	34.0
0	30.0

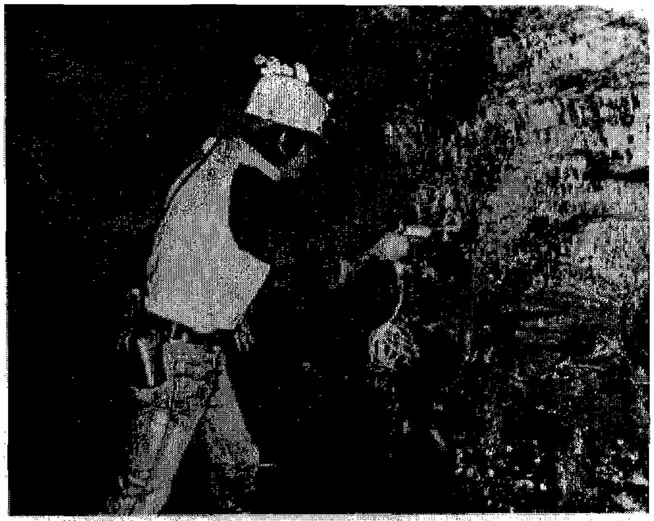


FIGURE 13

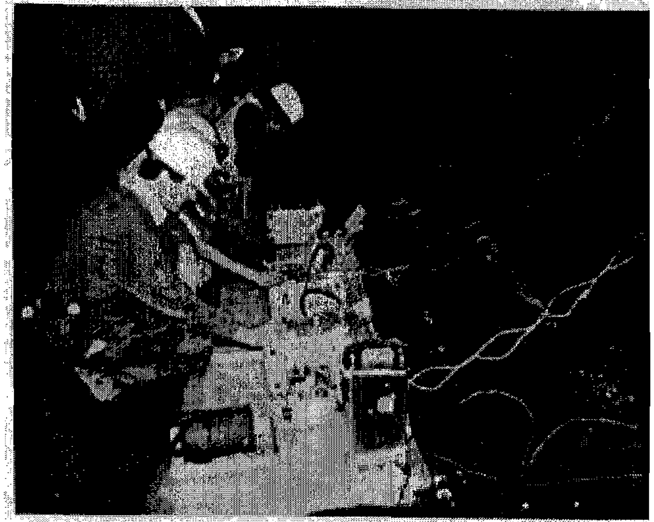
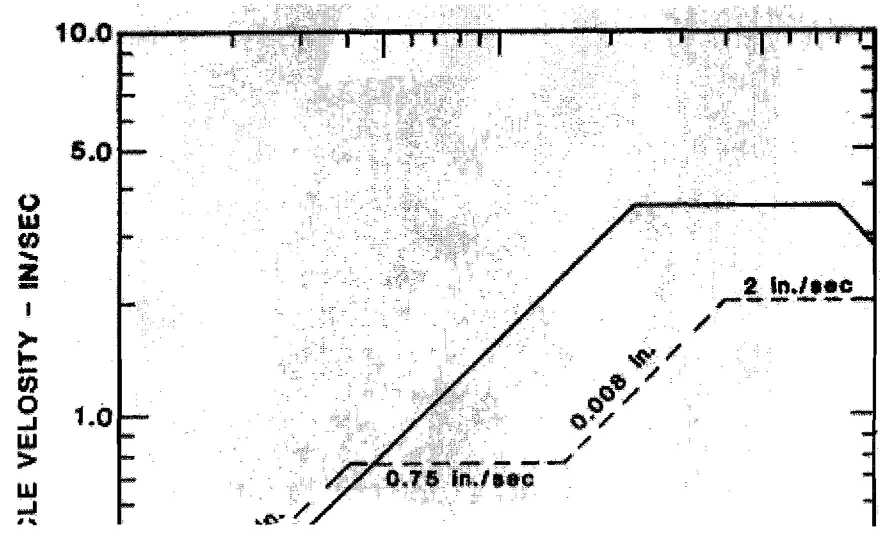
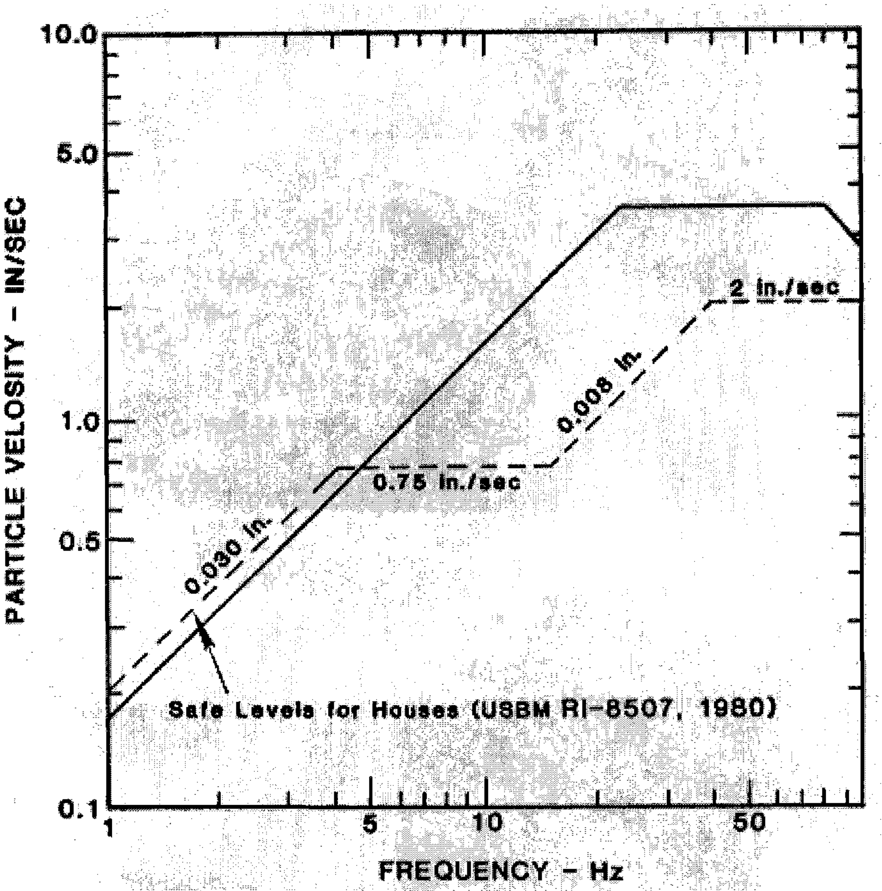


FIGURE 14





MAXIMUM DISPLACEMENT .0224 Inches

MAXIMUM VELOCITY 3.591 In/Sec

MAXIMUM ACCELERATION 1636.5288 In/Sec/Sec

FIGURE 15

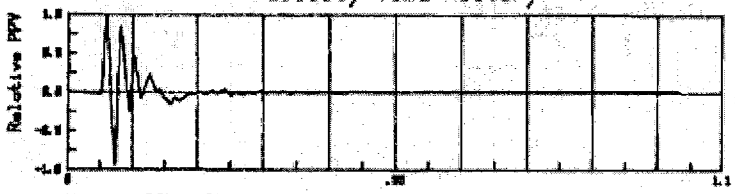
OSM PROJECT - BLAST INDUCED UNDERGROUND VIBRATION

HOLE NO: # 5
CHARGE WEIGHT: 302 LB
EQUIPMENT NO: 6114
STATION NO: STA. 7

DATE: 5/11/83

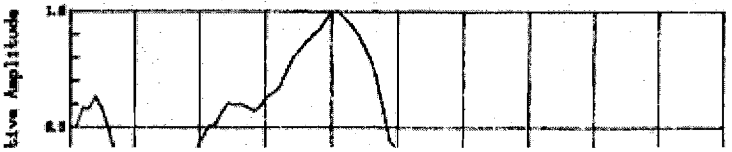
FOURIER #
83-165-30FV

Velocity Time History



Maximum PPV= .225 in/sec
Time interval= .002 sec

Frequency Spectrum (Magnitude)



OSM PROJECT - BLAST INDUCED UNDERGROUND VIBRATION

HOLE NO: # 5
CHARGE WEIGHT: 302 LB
EQUIPMENT NO: 6114
STATION NO: STA. 7

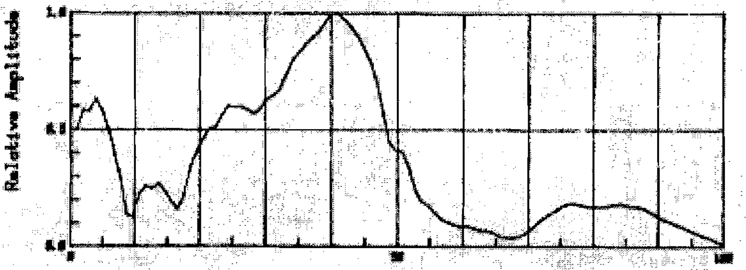
DATE: 5/11/83

FOURIER #
83-165-30FV


Velocity Time History

Maximum PPV= .225 in/sec
Time interval= .002 sec

Time (sec)


Frequency Spectrum (Magnitude)

Maximum Amplitude is .005 in/sec/Hz
at Frequency 41 Hz

Frequency (Hz)

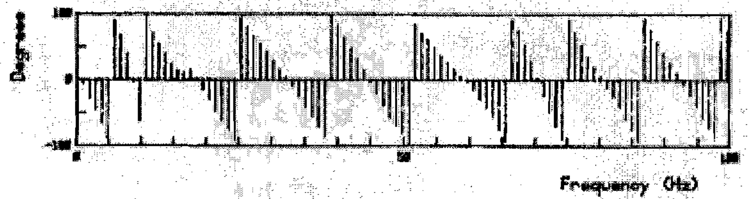

Frequency Spectrum (Phase)

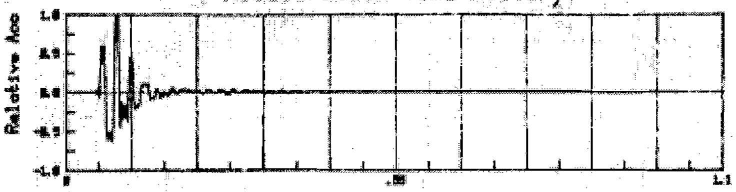
FIGURE 16

OSM PROJECT - BLAST INDUCED UNDERGROUND VIBRATION

HOLE NO: # 5
CHARGE WEIGHT: 302 LB
EQUIPMENT NO: 6114
STATION NO: STA. 7

DATE: 5/11/83

FOURIER #
83-165-30FV

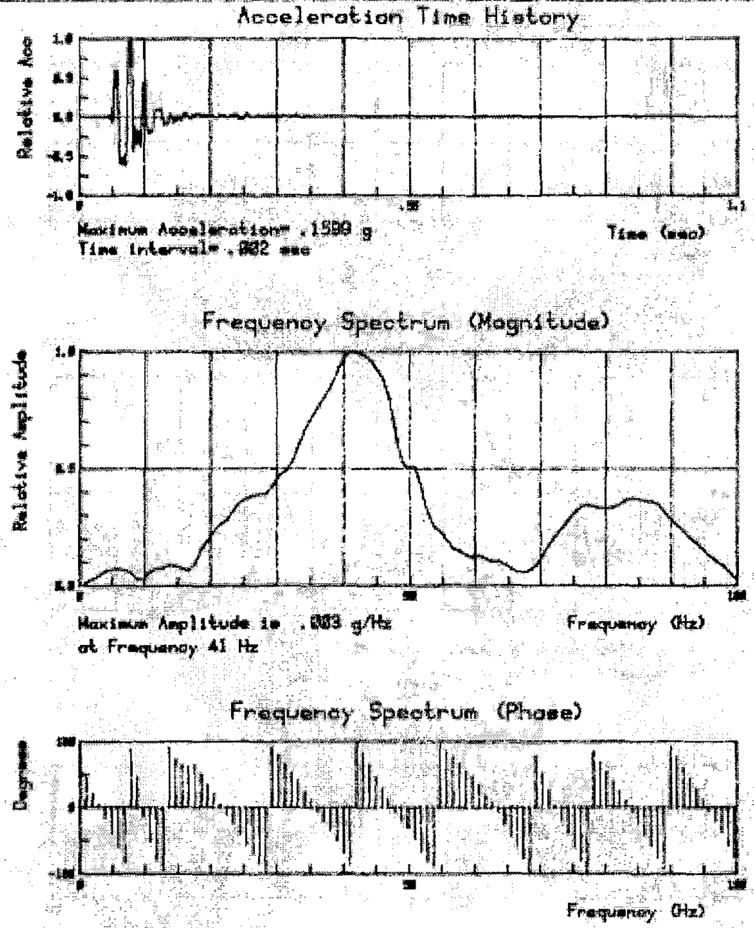

Acceleration Time History

Maximum Acceleration= .1509 g
Time interval= .002 sec

Time (sec)


Frequency Spectrum (Magnitude)

OSM PROJECT - BLAST INDUCED UNDERGROUND VIBRATION
HOLE NO: # 5
CHARGE WEIGHT: 302 LB
DATE: 5/11/83
EQUIPMENT NO: 6114
STATION NO: STA. 7
FOURIER #
83-165-38FV

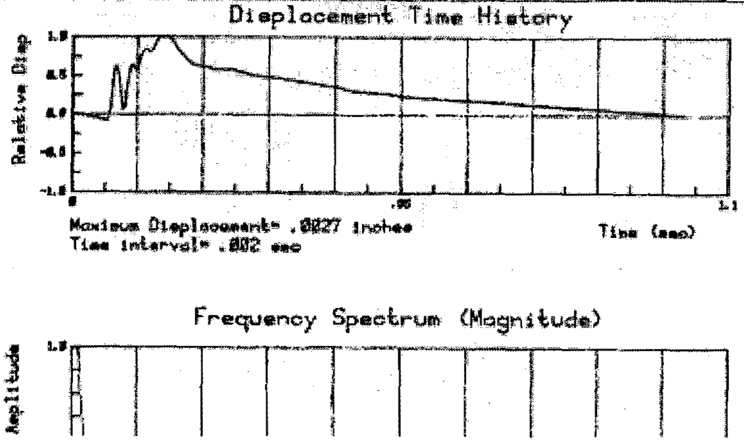


Maximum Acceleration= .1599 g
Time interval= .002 sec

Maximum Amplitude is .003 g/Hz
at Frequency 41 Hz

FIGURE 17

OSM PROJECT - BLAST INDUCED UNDERGROUND VIBRATION
HOLE NO: # 5
CHARGE WEIGHT: 302 LB
DATE: 5/11/83
EQUIPMENT NO: 6114
STATION NO: STA. 7
FOURIER #
83-165-38FV



Maximum Displacement= .0027 inches
Time interval= .002 sec

OSM PROJECT - BLAST INDUCED UNDERGROUND VIBRATION

HOLE NO: # 5
CHARGE WEIGHT: 302 LB
EQUIPMENT NO: 6114
STATION NO: STA. 7

DATE: 5/11/83

FOURIER #
83-165-38FV

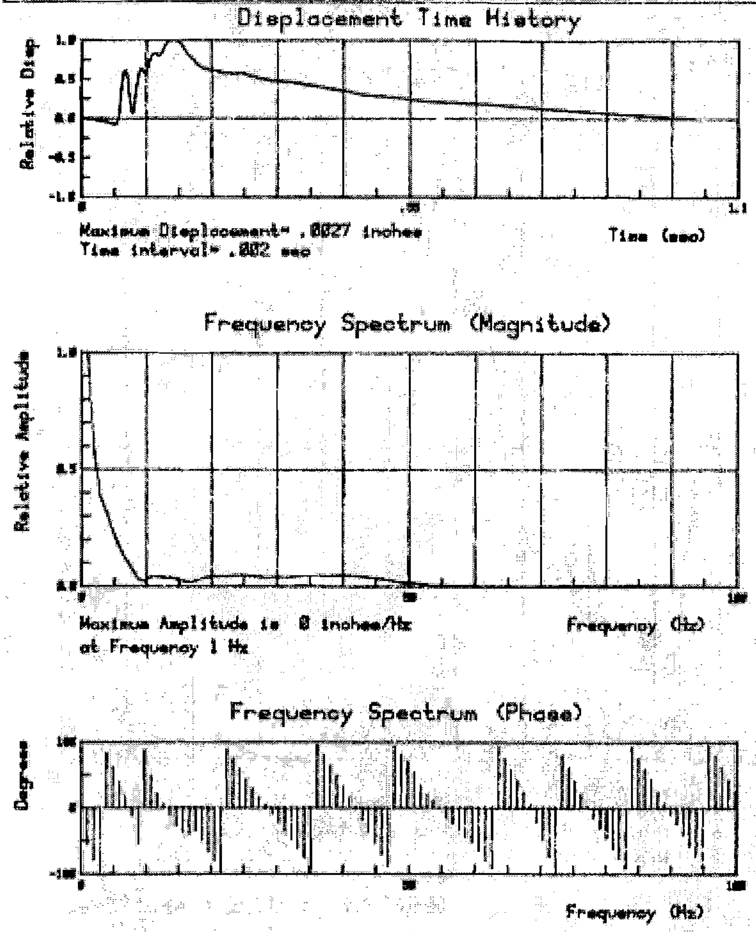


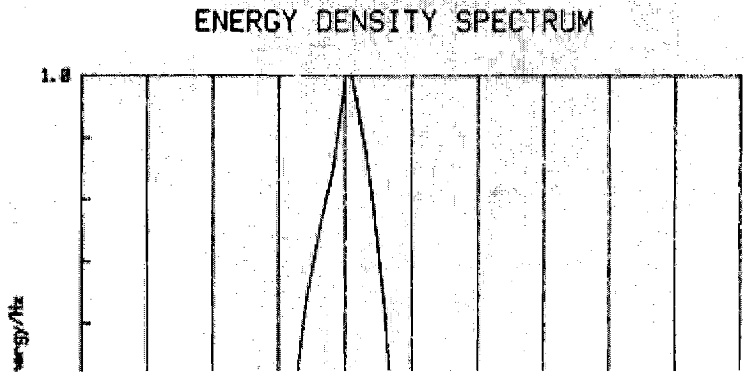
FIGURE 18

OSM PROJECT - BLAST INDUCED UNDERGROUND VIBRATION

HOLE NO: # 5
CHARGE WEIGHT: 302 LB
EQUIPMENT NO: 6114
STATION NO: STA. 7

DATE: 5/11/83

FOURIER #
83-165-38FV



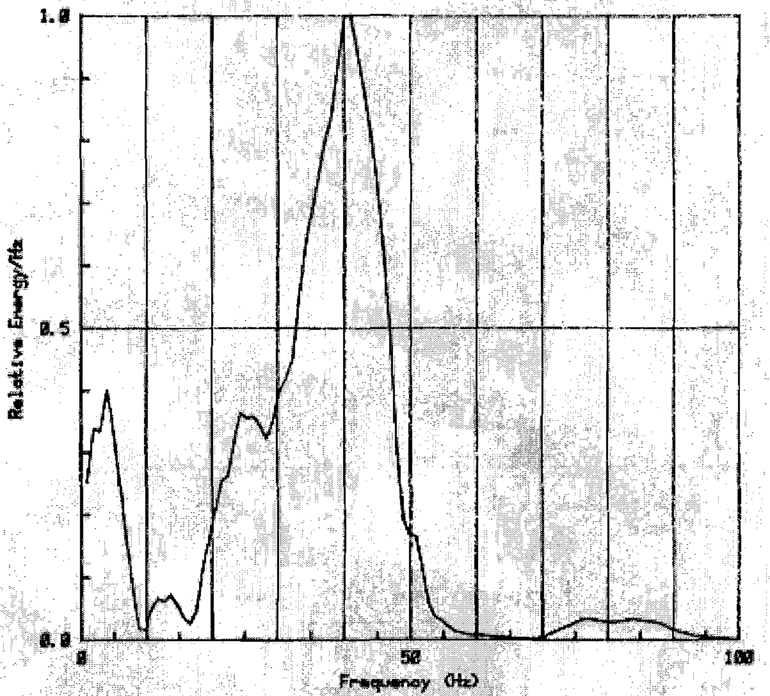
OSM PROJECT - BLAST INDUCED UNDERGROUND VIBRATION

HOLE NO: # 5
CHARGE WEIGHT: 302 LB
EQUIPMENT NO: 6114
STATION NO: STA. 7

DATE: 5/11/83

FOURIER #
83-185-30FV

ENERGY DENSITY SPECTRUM



Maximum Energy Density Spectrum is 0 (in/sec)^2*sec/Hz
at Frequency 41 Hz

TOTAL ENERGY DENSITY SPECTRUM .0002 (in/sec)^2*sec

FIGURE 19

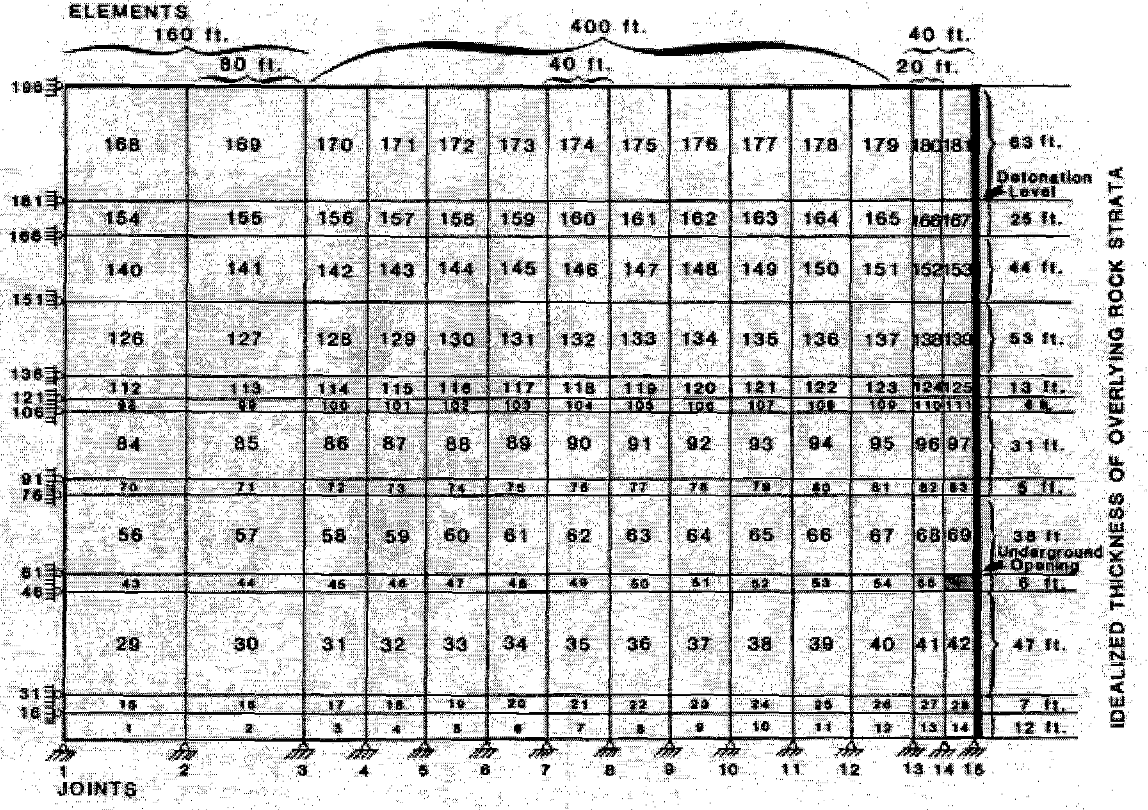

ELEMENTS
160 ft.
80 ft.
400 ft.
40 ft.
40 ft.
20 ft.
63 ft.
Detonation Level
25 ft.
44 ft.
53 ft.
13 ft.
6 ft.
31 ft.
5 ft.
38 ft.
Underground Opening
6 ft.
47 ft.
7 ft.
12 ft.
IDEALIZED THICKNESS OF OVERLYING ROCK STRATA
JOINTS
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
31
46
61
76
91
106
121
136
151
166
181
196

FIGURE 20