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Seismic Detection of Trapped Miners Using In-Mine Geophones

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Seismic Detection of Trapped Miners Using In-Mine Geophones

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ILLUSTRATIONS

SEISMIC DETECTION OF TRAPPED MINERS USING IN-MINE GEOPHONES

by

James A. Powell[1] and Richard A. Watson[2]

ABSTRACT

A seismic system which utilizes in-mine geophones to detect trapped miners has been developed. Tests at the Bureau of Mines Safety Research Mine at Bruceton, Pa., and at two operating mines indicate such a system has a maximum detection range in excess of 1,000 feet. The system is fieldworthy and portable and requires less than 30 minutes to set up and check. Real-time detection is possible.

INTRODUCTION

In 1970, the National Academy of Engineering[3] reported that a seismic system might be capable of detecting and locating trapped miners. They described a system in which the miners would strike the floor, rib, or roof of the mine with a sledge, a roof beam, or any other large, heavy object they could find. The resulting vibrations would travel to the surface where they would be converted to electric signals by seismic transducers (geophones). These signals would be amplified, filtered, and recorded. By comparing arrival times at several different geophone locations, the trapped miner would be located.

In 1971 and 1972, under Bureau of Mines contracts H0101262 and H0210063, Westinghouse Electric Co. built and tested such a system. Under certain favorable combinations of geologic conditions, mine depth, and background noise, the system worked. However, when the system was taken to actual mine disasters, measurement at the disaster site indicated that the noise generated by surface rescue equipment would mask any signals the trapped miner could generate. Thus, times specifically designated for seismic "listening" must be allocated and enforced.

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[3]National Academy of Engineering, Committee on Mine Rescue and Survival Techniques. Mines Rescue and Survival. National Technical Information Service, PB 191 691, 1969.

One possible way of reducing the effect of surface noise is to place the geophones in the mine. As with the surface system, the trapped miner would generate a signal by striking the mine rock. The resulting vibrations would be detected by geophones placed in the mine. This requires that geophones be installed in the mine prior to a disaster, or that they be installed by a rescue crew as part of the postdisaster procedure. This report describes the makeup and testing of an in-mine seismic system for the detection of trapped miners. No location has been attempted with this system.

ACKNOWLEDGMENTS

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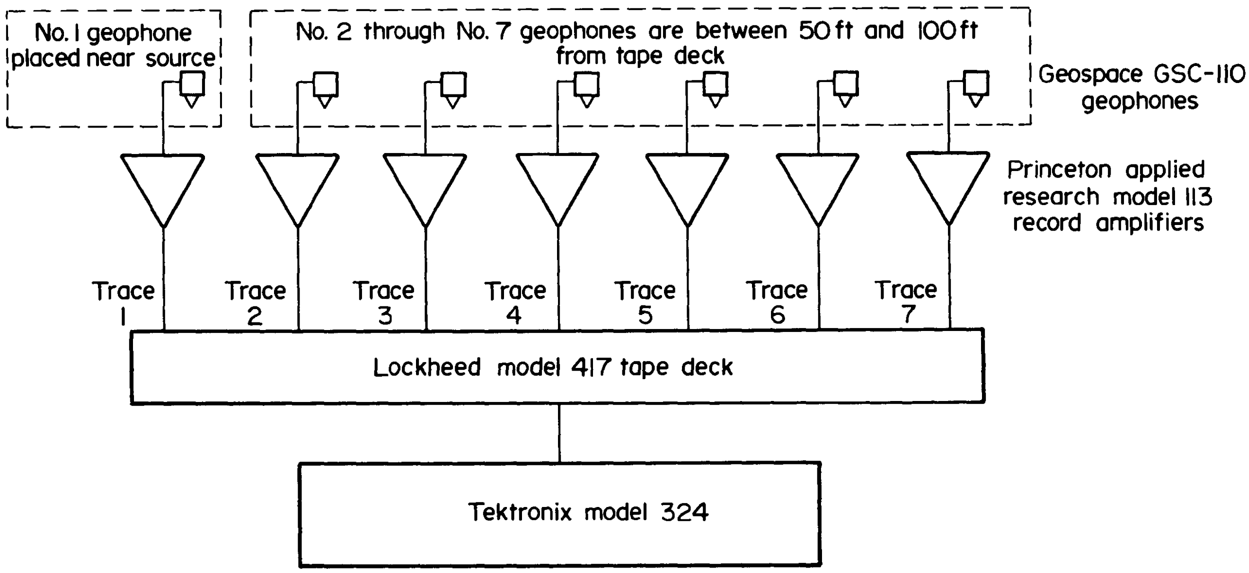
THE SEISMIC SYSTEM

Several geophone placement techniques have been tried. In one method a geophone was planted in the mine floor and buried under several inches of dirt. This burying reduced the effect of airborne sound and improved coupling of the geophone to the earth. In some tests several geophones were connected to give a single output. Series, parallel, and series-parallel combinations were used. This is referred to as a geophone "array"; in these tests most arrays consisted of six geophones in a hexagonal pattern. The hexagon has



Note-The listing of brand names and model numbers is for informational purposes only, and is not intended to imply endorsement of any equipment

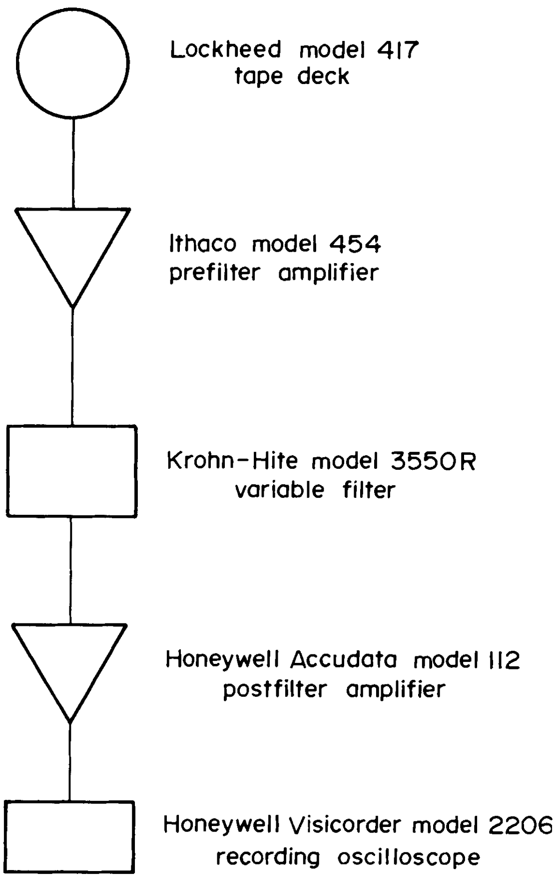
FIGURE 1. - Schematic of recording system.

sides about 6 feet long. The array geophones are planted in the floor and buried in the same manner as the individual floor geophone.

Since mine floors are frequently muddy and/or are underlaid by incompetent rock, some geophones were attached to roof bolts. As will be discussed later, resin-grouted bolts were preferred but were not always available. The roof bolts provided a firm coupling of transducer to competent rock.

The output of the geophone was recorded on a seven-track tape deck. Since geophone output is very small (usually much less than 1 millivolt), record amplifiers were required. Amplifier gains were varied from 20 db to 80 db, depending on the expected strength of the signal.

Figure 1 is a schematic of the recording system. The record amplifiers, tape deck, and oscilloscope are all battery powered. The geophones are passive transducers electrically isolated from ground. Hence, if capacitive coupling is negligible, the entire system is ungrounded.



Note-The listing of brand names and model numbers is for informational purposes only, and is not intended to imply endorsement of any equipment

FIGURE 2. - Schematic of playback system.

Figure 2 is a schematic of the playback system. Generally speaking the recorded signal is already at the appropriate level to drive the recording oscillograph. Thus the gains of both the prefilter and postfilter amplifiers are usually near unity and function primarily as impedance matching units. The filters are infinitely variable in the 2- to 20,000-Hz band with a rolloff of 24 db per octave.

The Tests

The experiments were made in a quiet region of the mine during maintenance shifts. Care was taken to reduce the effect of noise generated by the test equipment and test personnel. Geophones were planted in the floor or clamped to roof bolts as described above. The gains of the record amplifiers were adjusted so that the incoming signal was well above system background noise yet did not exceed the dynamic range of the system.

Figure 3 is a schematic of the deployed seismic system. The block labeled "Instrument package" consists of six geophones or geophone arrays, six recording amplifiers, the tape deck, and

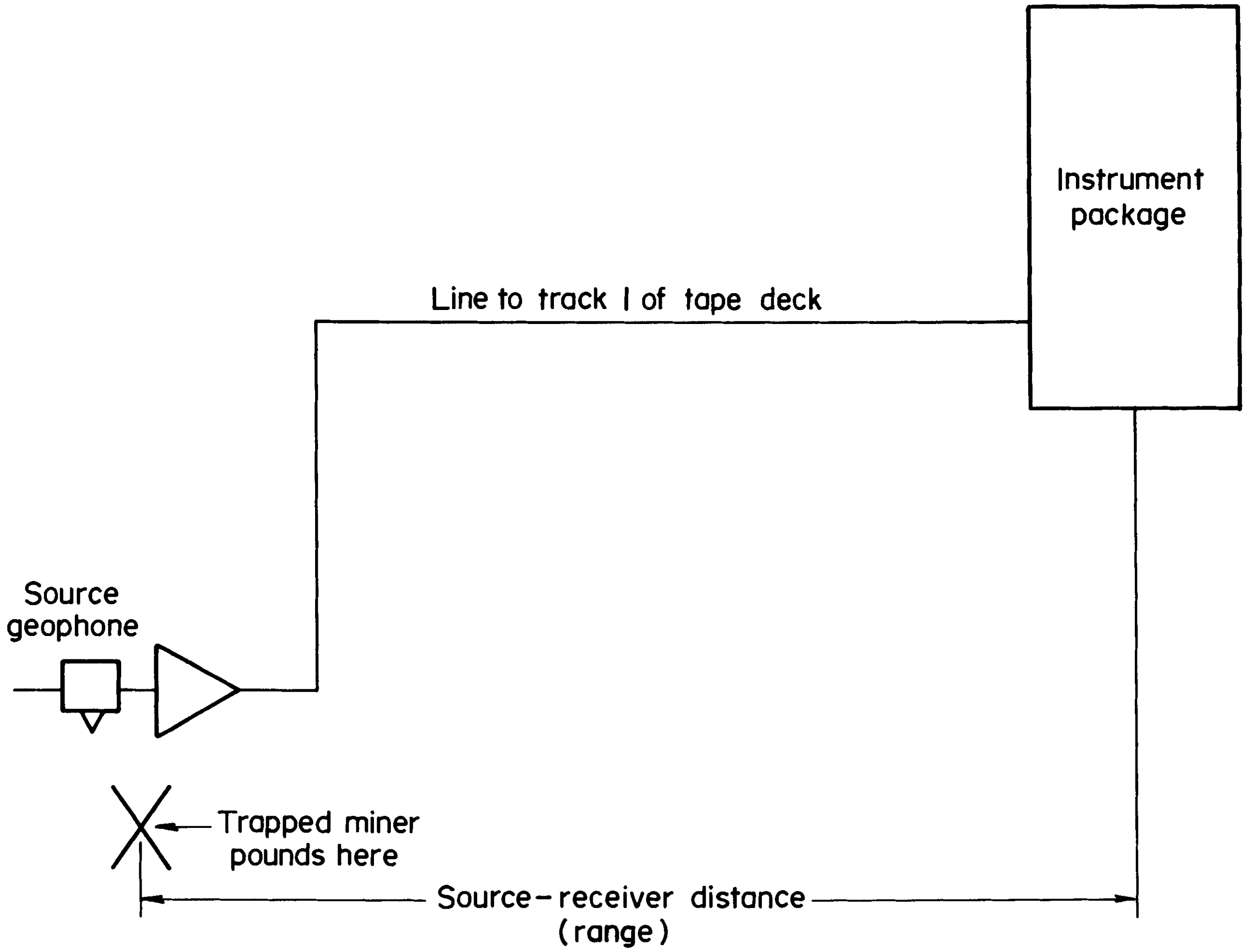


FIGURE 3. - Schematic of deployed system.

the oscilloscope. These are arranged as shown in figure 1. Figure 3 also shows that the output of a geophone placed near the source is wired back to track 1 of the tape deck. This geophone, referred to as the "source" geophone, is used to determine the time the seismic signal began.

The actual experiments, once the instruments have been deployed and checked, consist of--

1. Measuring the distance from the geophone to the place where the trapped miner will generate the signal.

2. Planting the source geophone within 15 feet of the trapped miner.

3. Striking a roof bolt (or floor or rib) 10 times. Usually a 5- to 10-pound draw bar or crow bar was used, although some tests were conducted using a 12-pound sledge, a timber, a geologist's pick, and even a hardhat.

4. Moving to the next location and repeating these steps.

Results

Figure 4 is a high-speed (1 inch equals 0.05 sec) playback of a test in which the source-receiver distance was about 550 feet. This record contains many features common to most of the recordings so it will be discussed in some detail. The top trace (trace 1) represents the signal at the source geophone. The second trace (trace 2) was recorded by a single geophone planted in the floor. Traces 3 and 4 were recorded from roof bolt geophones. Each of the last three traces represents the summed output of six geophones; that is, the arrays described above.

Traces 3 and 4 show very pronounced ringing. Such ringing is common in geophones attached to roof bolts. On traces 2, 6, and 7 two distinct arrivals are noted. By noting the arrival times at the source (on trace 1) and at the recording site (on traces 2, 6, and 7) and by noting the distance between them (550 feet in this case), a velocity can be computed. The first arrival has a velocity near 12,500 fps; we postulate that it is a p-wave. The peak amplitude is in the second arrival and has a velocity near 5,000 fps. Since the second arrival has the higher amplitude, it is probably the arrival of greatest interest to those trying to detect signals. Its amplitude will be discussed later.

Figure 4 represents the results of playing back through the 20- to 200-Hz bandpass setting on the filters. Tests have been made using no filters and

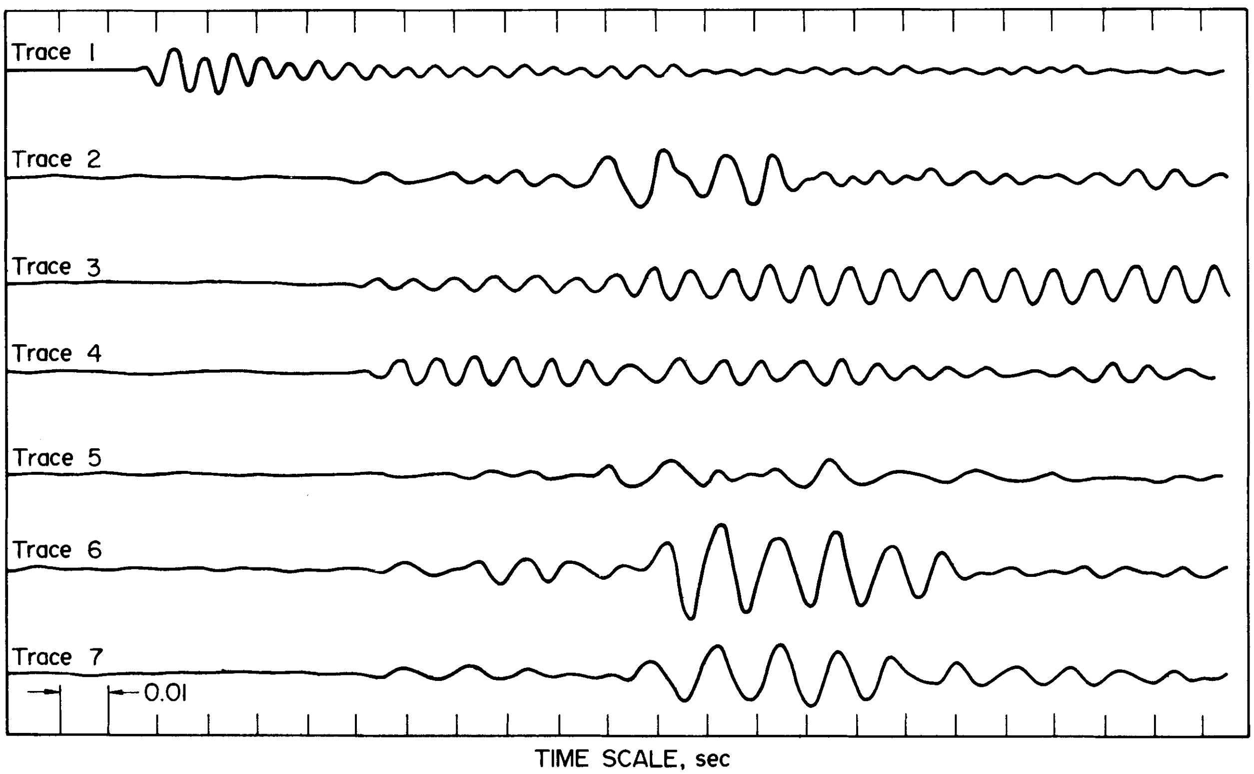


FIGURE 4. - Recording, source receiver distance 550 feet.

also using other filter settings. The 20- to 200-Hz setting seems to give the highest quality records.

Three trips to operating coal mines (two trips to the Arkwright mine, near Morgantown, W. Va., and one trip to the Loveridge mine, near Fairview, W. Va.) were made during this project. Typically 30 or 40 recordings were made during each visit. In lieu of individually describing each record, the results of all three trips are summarized below.

1. The records made when the source is not in the same entry as the receiver do not differ from those made when source and receiver are in the same entry. Hence it is concluded that the signals are not guided by the mine tunnel.

2. P-wave and second arrival velocities at the Arkwright mine are near 15,000 fps and 5,000 fps, respectively. These are somewhat higher than the velocities (12,500 fps and 5,000 fps) recorded at Loveridge mine.

3. Roof bolts held in place by an expansion anchor tend to resonate with a frequency slightly over 100 Hz. These bolts may ring for up to 1 sec following a single impulse. At the Bruceton Safety Research Mine a geophone was attached to a resin-grouted roof bolt. No ringing was encountered with that roof bolt. No resin-grouted roof bolts were available at the operating coal mines.

4. A 20- to 200-Hz bandpass filter setting gave the best results at both mines.

5. Arrays of six geophones did not perform noticeably better than single geophones. It is noted that arrays are useful in discriminating between signal and noise on the basis of the directional characteristics of these components. For example, in oil exploration geophone arrays are used to reduce horizontally propagating noise while reinforcing vertically propagating signal. We hypothesize that both signal and noise are generated in the mine and hence have the same directional characteristics. Thus the array does not improve signal-noise ratio.

6. The geophones used in the Loveridge mine were placed within 100 feet of an area undergoing retreat mining. Despite the considerable roof working and noise of roof falls, the system worked well.

7. At both operating mines, signals are clearly detectable at distances of more than 1,000 feet from the source and cannot be detected at distances of 1,500 feet. Hence the range of the system is between 1,000 and 1,500 feet.

Peak Amplitudes and Attenuation

To date we have seen no theoretical explanation of the second arrival in figure 4. We do not intend to provide such an explanation here. Instead, two empirical formulas describing signal attenuation will be discussed.

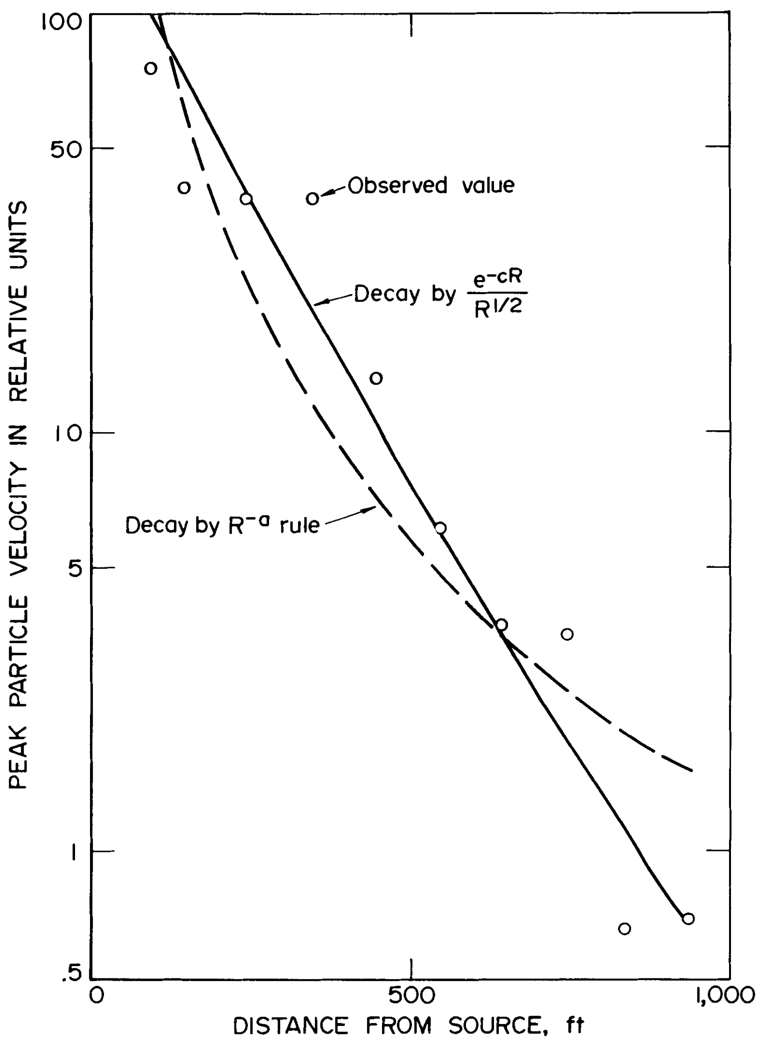


FIGURE 5. - Observed and predicted amplitudes.

In describing the attenuation of seismic waves produced by explosives, several Bureau of Mines investigators[4] used a relation in which peak particle velocity is assumed to decay as R^{-a}, where R is distance from the source and a is a constant in the range 1.1-1.6. The exact value of a in our tests depends on the mine and the geophone location, but least-squares fits indicate values for a of between 1.9 and 2.6 with a standard deviation on the order of 0.1. These values are appreciably higher than those in the explosive testing.

A better fit to experimental data was obtained assuming decay is proportional to $\frac{e^{-cR}}{R^{1/2}}$, where c is a constant which characterizes the mine geology and the geophone placement. When peak particle velocity is expressed in inches per second and range R is expressed in feet, c is near 0.004.

Figure 5 shows the observed and predicted amplitudes at the Loveridge mine for a single roof-bolt-mounted geophone. The dashed line indicates decay by an R^{-a} rule, where a = 1.98 with a standard deviation of 0.11. The solid line indicates decay by the $\frac{e^{-cR}}{R^{1/2}}$ rule, where c = 0.0045 with a standard deviation of 0.06. The residual variance using the first rule is 31.2; using the second rule it is 16.0. This indicates that the second rule is more accurate than the first.

[4]Condon, J. L., J. N. Murphy, and D. E. Fogelson. Seismic Effects Associated With an Underwater Explosive Research Facility. BuMines RI 7387, 1970, 20 pp.

CONCLUSIONS

The range of this system is between 1,000 and 1,500 feet. An emergency version of the system could be set up and checked in less than 30 minutes. Such a system would weigh about 100 pounds and fit in a 1- by 2- by 4-foot box. No elaborate signal processing would be required; real-time results are possible. An operational version of the test equipment would require one trunk that would be taken into the mine, one trunk containing spare parts and repair equipment, and a third trunk that would contain filters and other equipment to allow more detailed data processing.

Geophones should be attached to resin-grouted roof bolts when available, or to firmly set conventional bolts when necessary. The best signal-generating technique is to strike a roof bolt with a 5- to 10-pound metal bar. If it appears dangerous to strike the roof bolts, a competent portion of the mine roof, floor, or rib should be struck. When a metal bar is not available, objects such as timbers, hammers, or even hardhats can be used as signal sources.

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