THE DETECTION AND MAPPING OF SUBTERRANEAN WATER BEARING CHANNELS

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ABSTRACT

This report presents the results of an experiment designed to determine the vibrational characteristics of subterranean voids. The objective of this research was to evaluate the resonance phenomenon, as reported by early investigators, as an appropriate mechanism for the development of a cavity detection and delineation tool.

The results of this experiment, while not entirely establishing the existence of resonance per se, establishes a diagnostic reverberant seismic event that shows much promise as a detection mechanism. In addition, the use of three-component seismometers, and particle trajectory analysis, brings the reflection method back into the realm of practicality.

INTRODUCTION

The history of attempts to devise a workable geophysical technique, capable of detecting and delineating underground cavities from the surface, is less than ten years old in the literature. These attempts, as evidenced by the extensive appended bibliography, span a broad spectrum of geophysical exploration methods. While most of these attempts have yielded some degree of success, the general consensus of these authors has been that conventional geophysical approaches to this problem do not appear adequate.

A sequence of seismic experiments, exhibiting a novel approach to the detection problem, has been reported by Watkins et al (1967), and by Godson and Watkins (1968). By actual field measurements over caverns in basalt, nuclear bomb craters in alluvium, and sink holes in carbonates, they detected a strong persistence of seismic activity in the immediate vicinity of these underground cavities for durations lasting up to four seconds after detonation of the explosive source. After the normal modes of seismic energy transmission had dissipated to non-measurable levels, they discovered a relatively intense, near-periodic disturbance manifesting all the characteristics of a resonance phenomenon. Consequently, they named this phenomenon "Cavity Resonance".

This seismic phenomenon to date has not been theoretically explained nor systematically investigated experimentally. The lack of an accurate description of the temporal and spatial characteristics of this resonant field certainly precludes a theoretical explanation. Hence, experimental data from a systematic study is needed for an understanding of this phenomenon, and for the development of an appropriate exploration tool. To this end a seismic study was initiated over a known, well-surveyed, near-surface cavern. This paper presents the results of the initial phase of this experiment.

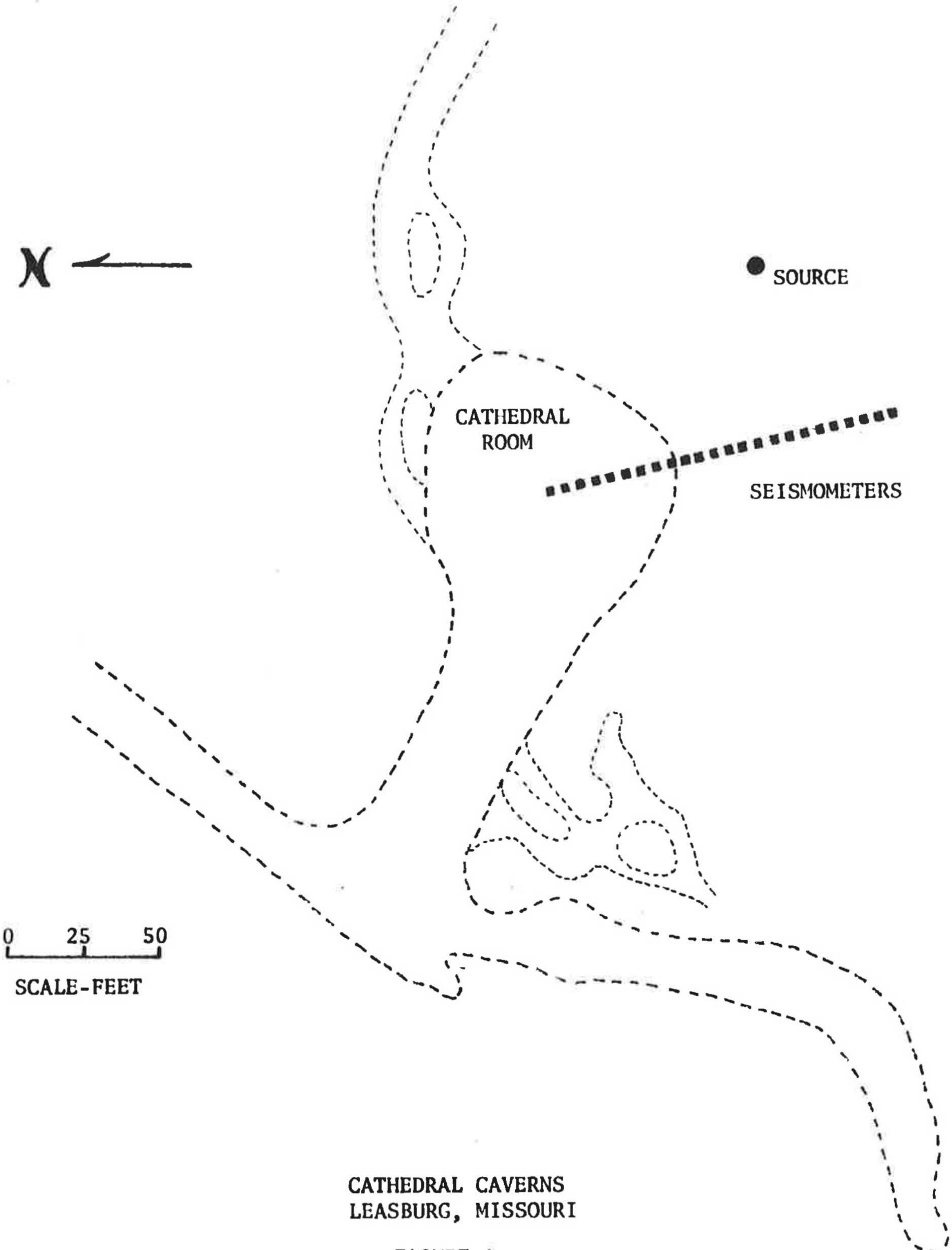
TEST CONFIGURATION

The cave system investigated is known as Cathedral Caverns, and is located approximately five miles due south of the town of Leasburg, Missouri. A sketch of this system is shown in Figure 1. The principal segment of the system investigated is known as the Cathedral Room. This room might best be described as an oblate spheroidal cavity with a minor and major axis of 30 and 40 feet respectively, and whose center lays roughly 145 feet below the ground surface. A single entrance to the northwest constitutes the only departure of this room from a closed cavity.

Three-component seismometers were placed, as shown in Figure 1, at five foot intervals along a traverse trending southwest from a point on the ground surface directly over the center of the cavity. Designating the seismometer location directly over the cavity center as Station 0, the source was located along a line that intersected the traverse at a right angle at Station 16. This source was approximately 55 feet from the line of traverse.

INSTRUMENTATION AND FIELD PROCEDURE

The ground velocity was measured with a single Sprengnether



CATHEDRAL CAVERNS
LEASBURG, MISSOURI

FIGURE I

Model S-6000 three-component short period seismometer. These measurements were recorded on a Dallas Instruments Model 7001 FM Instrumentation Recorder. The data was ultimately digitized and analyzed on an IBM 360-50 Digital Computer. The frequency response of the data acquisition system was flat from 2 to 200 Hertz with constant gain.

Data was obtained at 24 seismic stations. However, these measurements were not obtained simultaneously. Since the recording equipment was limited to three data channels plus an event marker, the data was obtained with 24 separate explosions at the same location.

One-third of a stick of dynamite was used as the explosive source. This charge was placed in a cavity filled with loose sand at a depth of three feet. All 24 shots were detonated in the same cavity. This cavity was originally prepared by compacting the walls by multiple explosions of small charges. The intent of of this preparation was to eliminate the generation of shear waves that normally cannot be reproduced. The explosion was contained by a five foot diameter metal cover loaded with 1,000 pounds of sand.

The data was checked for reproducibility, and the results insure a reasonable reproduction of the source characteristics. The source was placed broadside to enhance the delineation of direct arrivals from the source from the secondary arrivals from the cavity.

GEOLOGIC SETTING

The cavern is located within a relatively homogeneous section of dolomite, with intermittent layers of sand and shale, down to the basement complex at a depth of 1,500 feet. There are no known good reflecting horizons in this section.

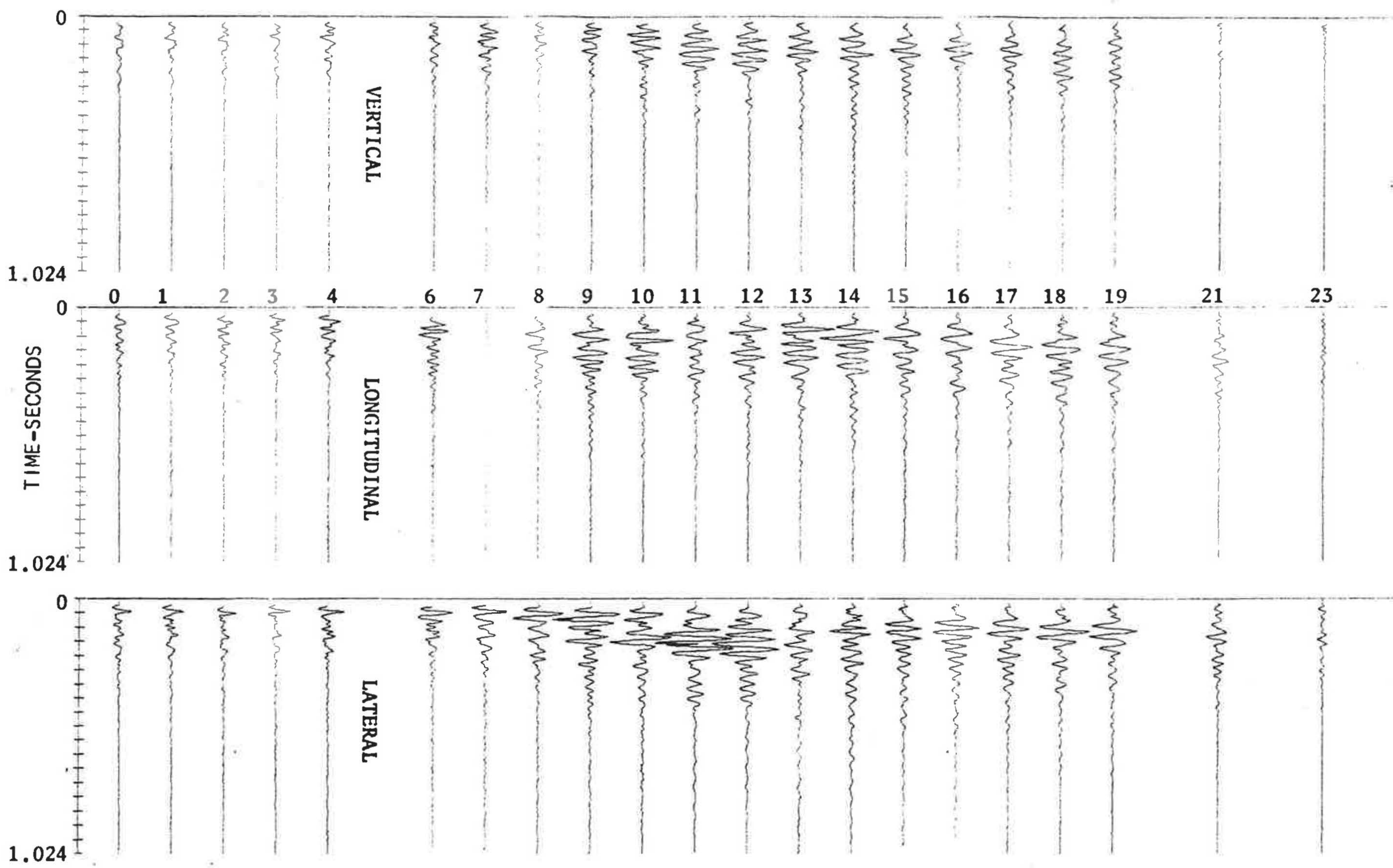
Bedrock is overlain by 10 to 15 feet of loose sandy soil, and the typical Ozark terrain is extremely rugged.

EXPERIMENTAL RESULTS.

Three-component data for 21 of the 24 stations is presented in Figure 2. Vertical deflections to the right, in this figure, indicate a downward motion of the seismometer. Longitudinal deflections indicate motion along a radial line extending from the point directly over the center of the cavity; deflections to the right correspond to horizontal motion away from the cavity. Lateral deflections to the right indicate horizontal motion perpendicular to this radial line and in a direction towards the side containing the source.

The principal objective of the analysis was to isolate those seismic events that were associated with the cavern, as opposed to those that would normally occur in its absence. Towards this objective, selected channels were analyzed for the particle trajectory characteristics. A typical analysis is shown in Figure 3. In this figure the various seismic events have been isolated and are presented in chronological order. Positive X corresponds to downward vertical motion. Positive Y corresponds to longitudinal motion away from the cavity. Positive Z corresponds to lateral motion towards the side containing the source. The arrows in these graphs indicate the direction of motion for increasing time.

In viewing the particle trajectory plots for several stations



0
1.024
0 1 2 3 4 6 7 8 9 10 11 12 13 14 15 16 17 18 19 21 23
TIME-SECONDS
VERTICAL
LONGITUDINAL
LATERAL

FIGURE 2

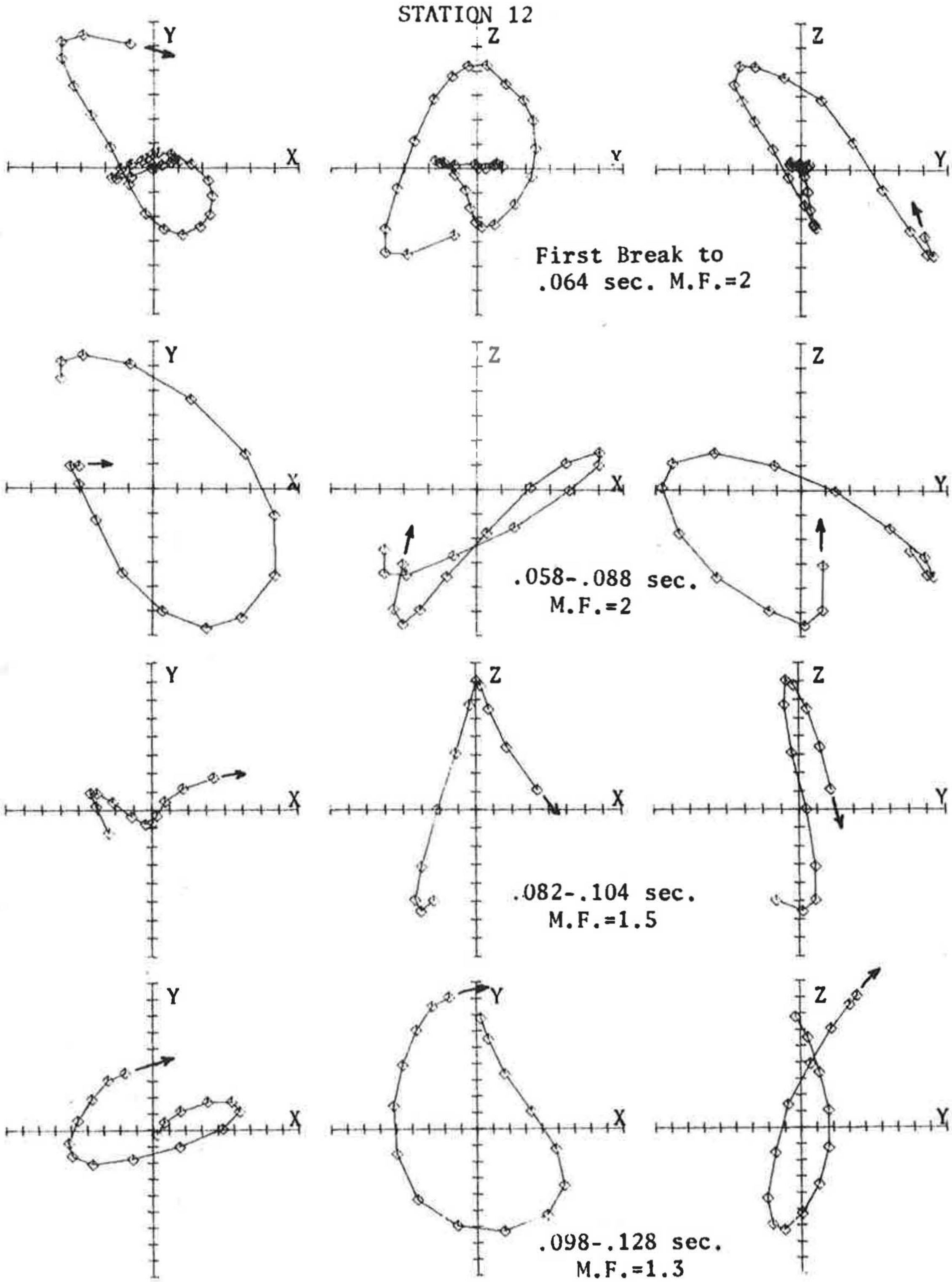

STATION 12
Y
X
Z
Y
Z
Y
First Break to
.064 sec. M.F.=2
Y
X
Z
X
Z
Y
.058-.088 sec.
M.F.=2
Y
X
Z
X
Z
Y
.082-.104 sec.
M.F.=1.5
Y
X
Y
X
Z
Y
.098-.128 sec.
M.F.=1.3

FIGURE 3

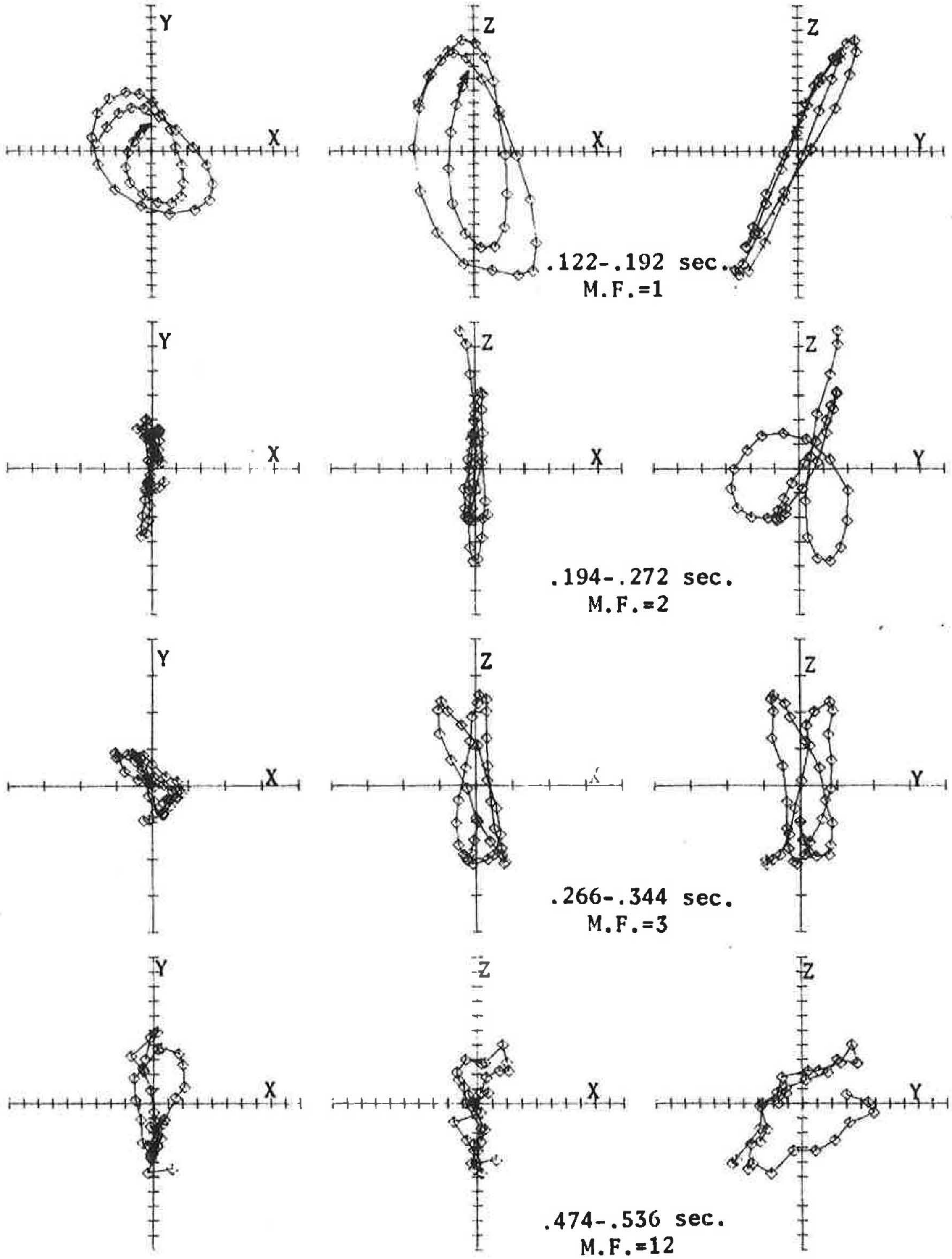


FIGURE 3 (con't)

in the central region of the traverse, the principal seismic events could be clearly correlated from station to station, and many of these events could be identified. The early events in the records are those that would normally be expected to occur. In reference to Figure 3, these events, in chronological order, are: (3a) a direct refraction plus a reflected compressional arrival from the cavern roof, (3b) a reflected shear wave arrival from the cavern roof, (3c) a reflected compressional arrival emanating from an unknown void to the east of the Cathedral Room, (3d) and (3e) direct Rayleigh waves from the source. These arrivals, which constitute the predominant character of each record, depend upon the source-cavern-sensor configuration for there existence. This early part of the record changes quite drastically, as would be expected, with a change in the source location. All of these events are traveling waves and involve vertical motion to a large extent.

The remaining seismic events, beginning with a record time of .194 seconds after the first break and lasting to the end of the record, exhibit a phenomenon quite distinct from the normal modes of energy transmission as occured in the early part of the record. These events are almost devoid of vertical components, are relatively insensitive to source location, occur only within a limited region of the traverse, and do not appear to have a propagating character.

Figure 4 is an enlarged version of Channel 12 of Figure 3. The time history of this record between the record times of .270 and .344 seconds is consistently preserved with drastic variations in the source location. This motion is oriented perpendicular to a radial line

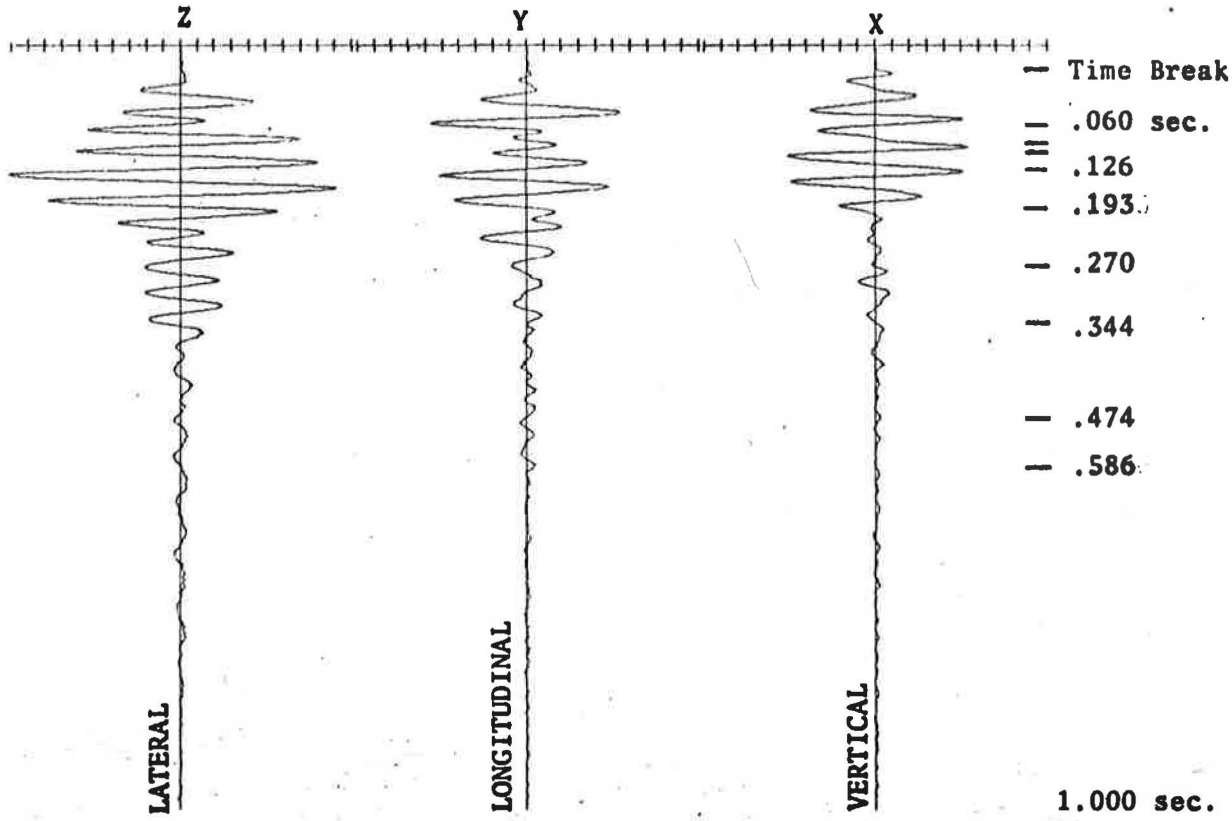

Z
Y
X
Time Break
.060 sec.
.126
.193
.270
.344
.474
.586
LATERAL
LONGITUDINAL
VERTICAL
1.000 sec.

FIGURE 4

drawn from the point directly over the center of the cavity, and consequently appears to be cavity oriented. The motion for later times also show this predominant orientation.

FURTHER EXPERIMENTATION

A limited investigation was conducted on a nearby segment of the same cavern system. This segment was the primary tunnel leading from the cave entrance to the Cathedral Room. The principal objective of this study was to determine if there existed any preferred orientation of the ground motion for late record times of the type observed for the Cathedral Room.

The data, unfortunately of poor quality, is not presented. However, the data showed that again the ground motion for late record times was entirely horizontal and parallel to the axis of the tunnel. This response, again, occured only within a limited region of the traverse, regardless of source location.

DISCUSSION OF RESULTS

The results of this experiment clearly demonstrate the necessity for three-component measurements in cavity detection problems. The compressional and shear wave reflections from the cavity roof were clearly distinguishable by means of the trajectory plots. The direction of propagation of those reflections arriving at a given station could be estimated, and by comparison of data for various stations along the traverse the general location of the reflecting surface could be determined by triangulation.

The ground motion for large record times appears to be of the SH (horizontally polarized shear wave) type with the exception that they do not appear to be connected in any way with the source location. Moreover, since they exist only over a limited region of the traverse, it appears doubtful that these disturbances are propagating. In the absence of simultaneous measurements, this propagational aspect could not be investigated.

The results of this experiment are inconsistent with those of Watkins et al, and Godson and Watkins. Their conclusions, as to the existence of resonance, were based on measurements taken only with vertical sensitive seismometers. The results of the current investigation show that the entire vertical record can be explained by traveling waves of the conventional type, with no other event occuring on the vertical trace that would not normally be expected.

The horizontally polarized motion, towards the later part of the record, is the only disturbance that might qualify as a resonance phenomenon. Further tests would reveal its propagational or non-propagational character. This disturbance is definitely cavity oriented. In the event that it is also propagating, this disturbance might possibly be classified as a wave guide effect.

Regardless of the physical nature of this disturbance, it provides a diagnostic for the detection and delineation procedure. Used in conjunction with the roof reflection data, an effective exploration tool looks promising.

PRESENTATIONS AND PUBLICATIONS

The preliminary results of this investigation were presented at the 41st International Meeting of the Society of Exploration Geophysics in Houston in November 1971. Two papers were presented: "Theory of Cavity Resonance", and "Detection and Delineation of Subterranean Cavities". Both papers were presented by the principal investigator.

The current results were presented at the Eighth American Water Resources Conference in St. Louis in October 1972. This presentation was published in the Short Papers of the Conference.

The full content of the results of this project has been submitted to the Society of Exploration Geophysics for publication.

TRAINING ACCOMPLISHMENTS

This project has resulted in the extensive training of Larry Gardner, an undergraduate Geophysics major, in the field of water resources. Moreover, through the use of the instrumentation developed through this project many students have been exposed to this and related water resources problems by actual class experience.

This project success relied heavily on the cooperation of Dr. James Tracy, of the Electrical Engineering Department, who developed the data processing technique. Through his efforts many students of Electrical Engineering were exposed to this project.

BIBLIOGRAPHY

Briston, C., 1966, A New Graphical Resistivity Technique for Detecting Air-Filled Cavities: Studies in Speleology, v. 1, Part 4, p. 204-227.

Colley, G. C., 1963, The Detection of Caves by Gravity Measurements: Geophysical Prospecting, v. 11, no. 1, p. 1-9.

Cook, J. C., 1964, Progress in Mapping Underground Cavities with Seismic Shear Waves: Trans. Soc. Min. Engrs., p. 26-32.

Cook, J. C., 1965, Seismic Mapping of Underground Cavities Using Reflection Amplitudes: Geophysics, v. 30, no. 4, p. 527-538.

Dutta, N. P., Bose, R. N., and Saikia, B. C., 1970, Detection of Solution Channels in Limestone by Electrical Resistivity Method: Geophysical Prospecting, v. 18, no. 3, p. 405-414.

Fisher, W., 1971, Detection of Abandoned Underground Coal Mines by Geophysical Methods: U. S. EPA, Water Pollution Control Research Series, Project 14010.

Godson, R. H., and Watkins, J. S., 1968, Seismic Resonance Investigation of a Near Surface Cavity in Anchor Reservoir, Wyoming: Bull. Assn. Engr. Geol., v. 5, no. 1, p. 27-36.

Habberjam, G. M., 1969, The Location of Spherical Cavities Using Tripotential Resistivity Techniques: Geophysics, v. 34, no. 5, p. 780-784.

Kennedy, J. M., 1968, A Microwave Radiometric Study of Buried Karst Topography: Geol. Soc. Am. Bull., v. 79, no. 6, p. 735-742.

Lange, A. L., 1965, Cave Detection by Magnetic Surveys: Cave Notes, v. 7, no. 6, p. 41-56.

Love, C. L., 1967, A Geophysical Study of a Highway Problem in Limestone Terrain: Engr. Geol. Bull., v. 4, no. 1, p. 50-62.

Meyers, A. J., 1963, Sonar Measurements of Brine Cavity Shapes: Proceedings of Symposium on Salt, North Ohio Geol. Soc., Cleveland Ohio, p. 546-554.

Oberste-Lehn, 1966, Remote Sensors for Detecting Underground Cavities: Rand Corp. ARPA Contract SD-79, DDC No. AD 372 709.

Palmer, L. S., 1954, Location of Subterranean Cavities by Geoelectrical Methods: Mining Magazine, v. 91, no. 3, p. 137-141.

Watkins, J. S., Godson, R. H., and Watson, D., 1967, Seismic Detection of Near Surface Cavities: U. S. Geological Survey Prof. Paper No. 599-A.