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A SEISMIC INVESTIGATION OVER A NEAR-SURFACE CAVERN

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ABSTRACT

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A field experiment was conducted over a near-surface cavern with the principal objective of obtaining a spatial definition of the associated Cavity Resonance phenomenon, as reported by Watkins et al. (1967) and by Godson and Watkins (1968). The results of the experiment were inconsistent with those of the earlier investigators in that all seismic events recorded in the vicinity of the cavity, having vertical velocity components, could be readily identified as standard modes of seismic wave transmission.

A persistence of strong horizontal motion was observed for late record times. This horizontal motion was consistently oriented parallel to the cavity boundary, occurred only over an extremely limited range of the traverse at approximately a 25° polar angle to the vertical axis passing through the center of the void, and did not appear to be propagating. This energy might qualify as a cavity resonance phenomenon.

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 the authors has been that conventional geophysical approaches to the 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 an explosive source. This relatively intense disturbance was near-periodic and manifested 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 are 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 south of the town of Leasburg, Missouri. A sketch of this system is shown in Fig.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 minor and major axes of 30 and 40 ft., respectively. The center of the room lies approximately 145 ft. 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 Fig.1, at five foot intervals along a traverse trending southwest from a ground surface point located directly over the center of the cavity. Designating the seismometer location directly over the cavity center as Station O, the source was located along a line that intersected the traverse at a right angle at Station 16. This source was approximately 45 ft. from the line of traverse.

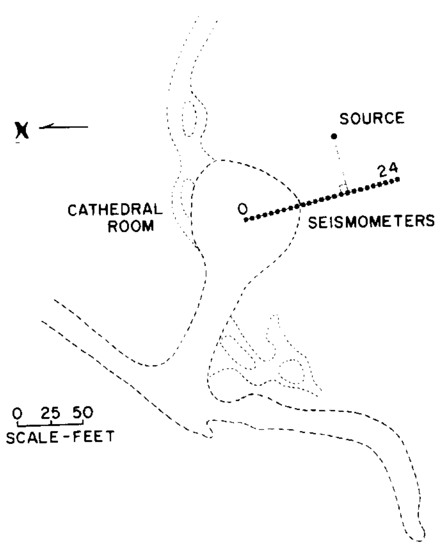

Fig.1. Plan view of the Cathedral Cavern System and seismometer array.

INSTRUMENTATION AND FIELD PROCEDURE

The ground velocity was measured with a single, Sprengnether Model S-6000, three-component, short period seismometer. The measurements were recorded on a Dallas Instruments Model 7001, FM Instrumentation Recorder. The data were ultimately digitized at a 1-msec sampling rate and analyzed on an IBM 360-50 Digital Computer. The frequency response of the data acquisition system was flat from 2 to 200 Hz with constant gain.

Data were obtained at 24 seismic stations; however, the measurements were not obtained simultaneously. Because the recording equipment was limited to three data channels plus an event marker, the data were 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 to a depth of 3 ft. All 24 shots were detonated in the same cavity. This cavity was originally prepared by compacting the walls with multiple explosions of small charges. The intent of this preparation was to eliminate the generation of shear waves that normally cannot be reproduced. The explosion was contained by a 5-ft. diameter metal cover loaded with 1,000 pounds of sand.

The data were checked for reproducibility, and the results ensure 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 which contains thin intermittent layers of sand and shale. The section extends to the basement complex at a depth of 1,500 ft. There are no known good reflecting horizons in this section. The dolomite bedrock is overlain by 10—15 ft. of loose sandy soil. The Ozark terrain in the area is typically rugged and has a moderate amount of relief.

EXPERIMENTAL RESULTS

Three-component data for 21 of the 24 stations are presented in Fig.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. Transverse 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

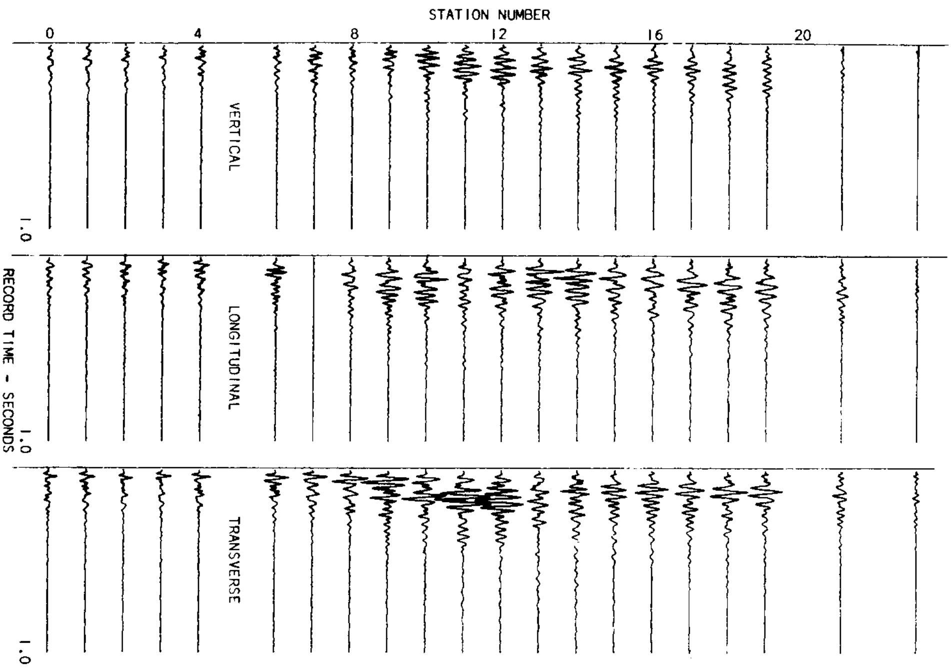

Fig.2. Three-component time histories. Transverse measurements are parallel to cavity boundary.

for the particle trajectory characteristics. A typical analysis is shown in Fig.3. In this figure, the various seismic events observed at Station 12 have been isolated and are presented in chronological order. For reference to the actual time history of the velocity components, the data of Station 12 are presented in an expanded view in Fig.4.

The particle trajectory plots of Fig.3 are shown with various degrees of magnification, designated as M.F. in these figures. The UP-vertical and CAVE-horizontal directional orientation of the seismometer components are indicated in this figure. The transverse motion towards the side containing the source is designated as (T). An arrow at the extremity of each time plot indicates the direction for increasing time.

In reference to Fig.4, the principal seismic events are presented in chronological order. For each distinguishable event a correlation from station to station was attempted with the principal objective of determining the point, or region, of origin of the emerging wave. In Fig.4a the principal event appears to be a shear wave reflection from the cavern roof in the lateral proximity of Station 8. As an illustration of the interpretation procedure, this event is shown for Stations 0, 4, 8, and 12 in Fig.5, and the interpretation of the data relative to the point of origin is shown by triangulation of the horizontal component of the direction of travel in Fig.6. This event appears to be, essentially,

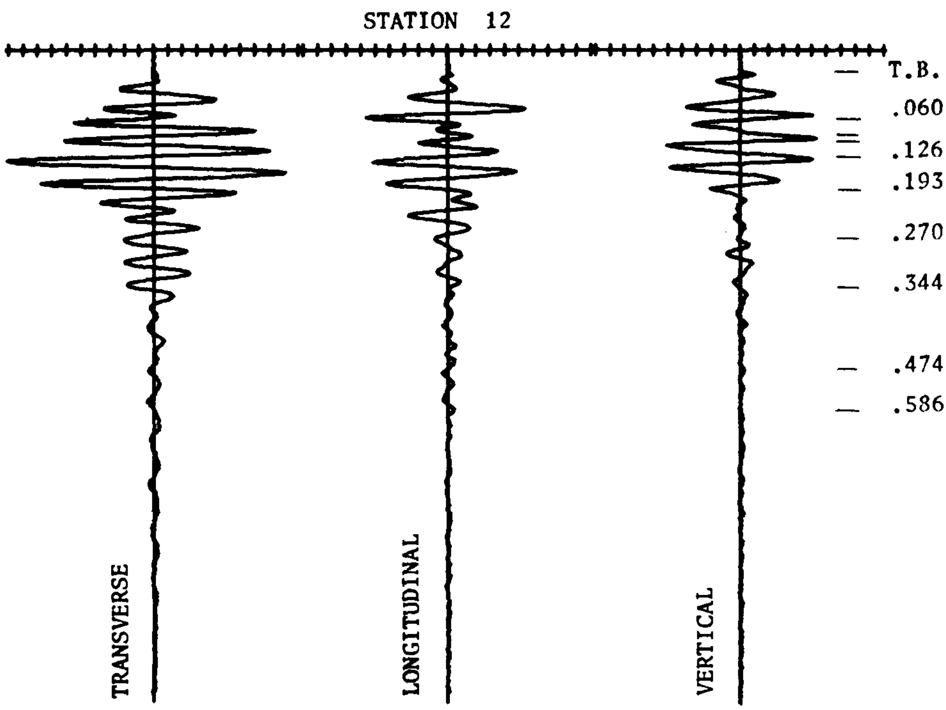

Fig.3. Particle trajectories for Station 12.

horizontally polarized, whereas the next advent, as shown in Fig.4b, which also appears to have its point of origin at the cavity roof, is a shear arrival of the more general variety.

Fig.4c shows an event which was not correlatable with either the known cavity boundaries nor the source. Fig.4d and 4e are direct Rayleigh waves from the source, followed by a SH source-oriented surface wave in Fig.4f.

The sequence of seismic events, Fig.4a—4f, constitute the predominant character of each record and depend upon the source-cavern-sensor configuration for their existence at a given location. 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 travelling waves and involve vertical motion to a large extent, with the exception of the SH events of Figs.4a and 4f. However, the next event, Fig.4g, exhibits a phenomenon quite distinct from the typical modes of energy transmission as occured in the earlier part of the record. This event is almost devoid of a vertical component, occurs only within a limited region of the traverse, and does not appear to have a propagating character. From a preliminary investigation, this event also appears to be relatively insensitive to source location.

The predominant SH-type particle motion for the event of Fig.4g is oriented perpendicular to a radial line drawn from the point directly over the center of

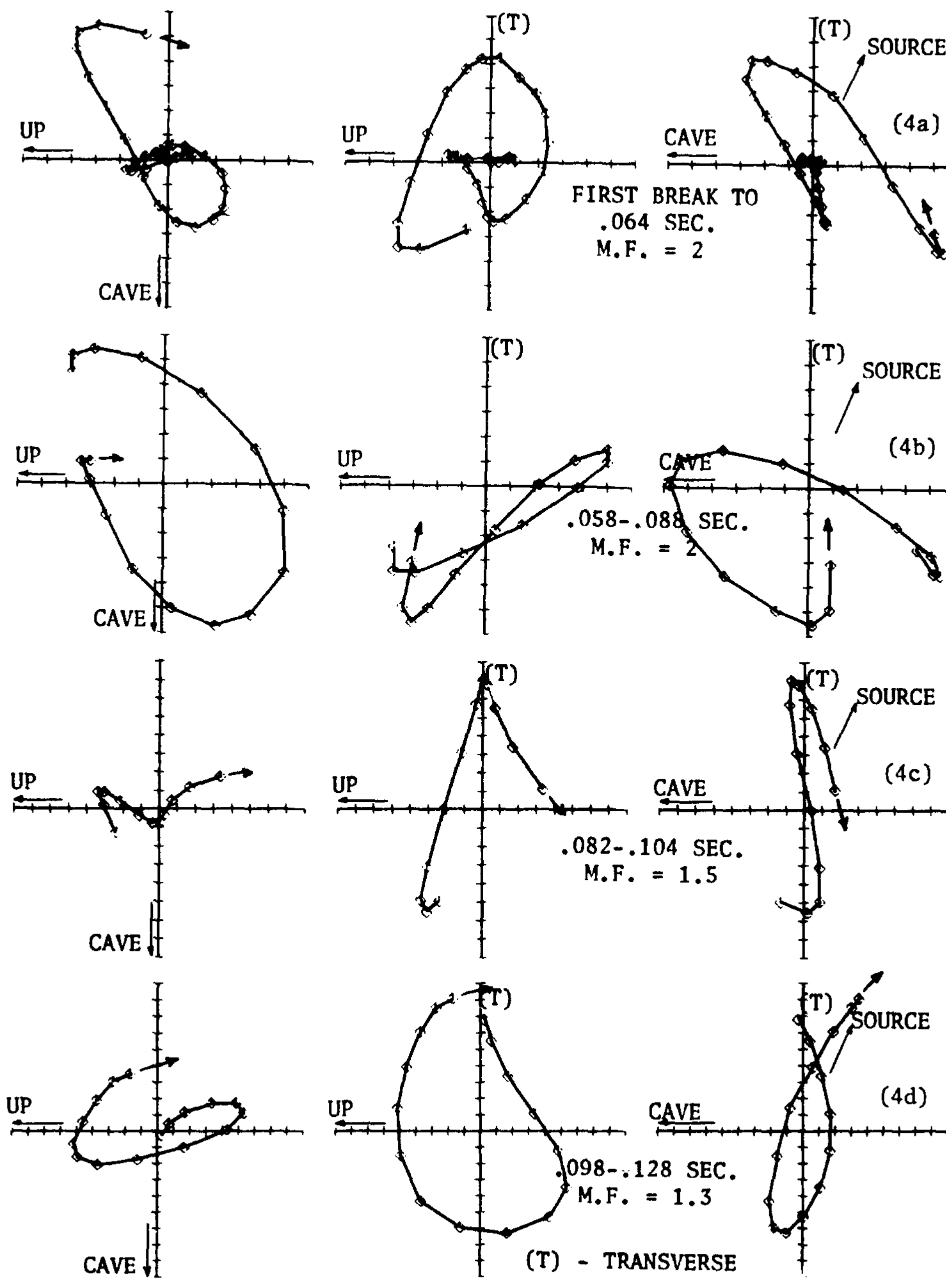

Fig.4. Three-component data for Station 12. Transverse measurements are parallel to cavity boundary.

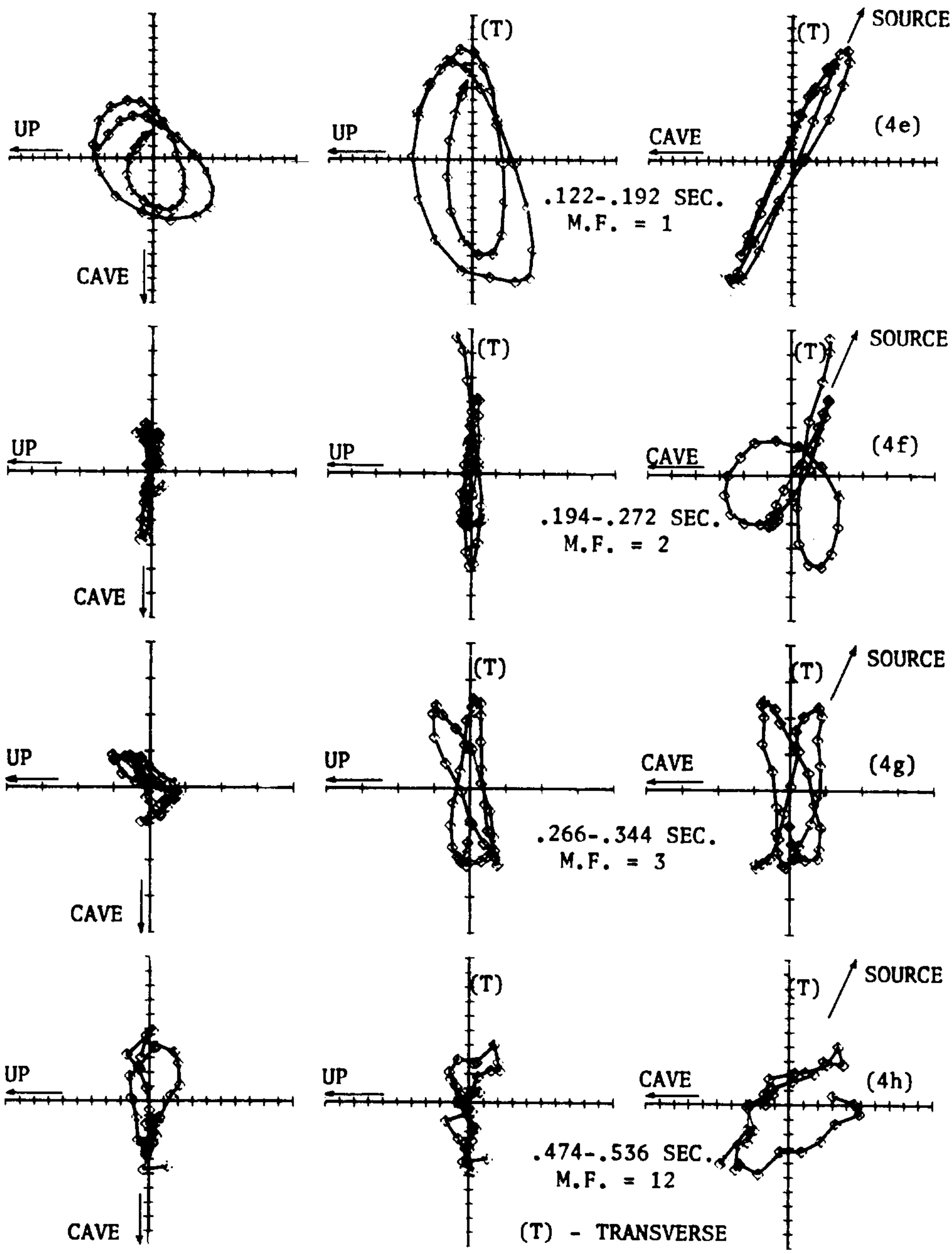
UP
CAVE
(T)
SOURCE
(4e)
.122-.192 SEC.
M.F. = 1
(4f)
.194-.272 SEC.
M.F. = 2
(4g)
.266-.344 SEC.
M.F. = 3
(4h)
.474-.536 SEC.
M.F. = 12
(T) - TRANSVERSE

Fig.4 (cont.)

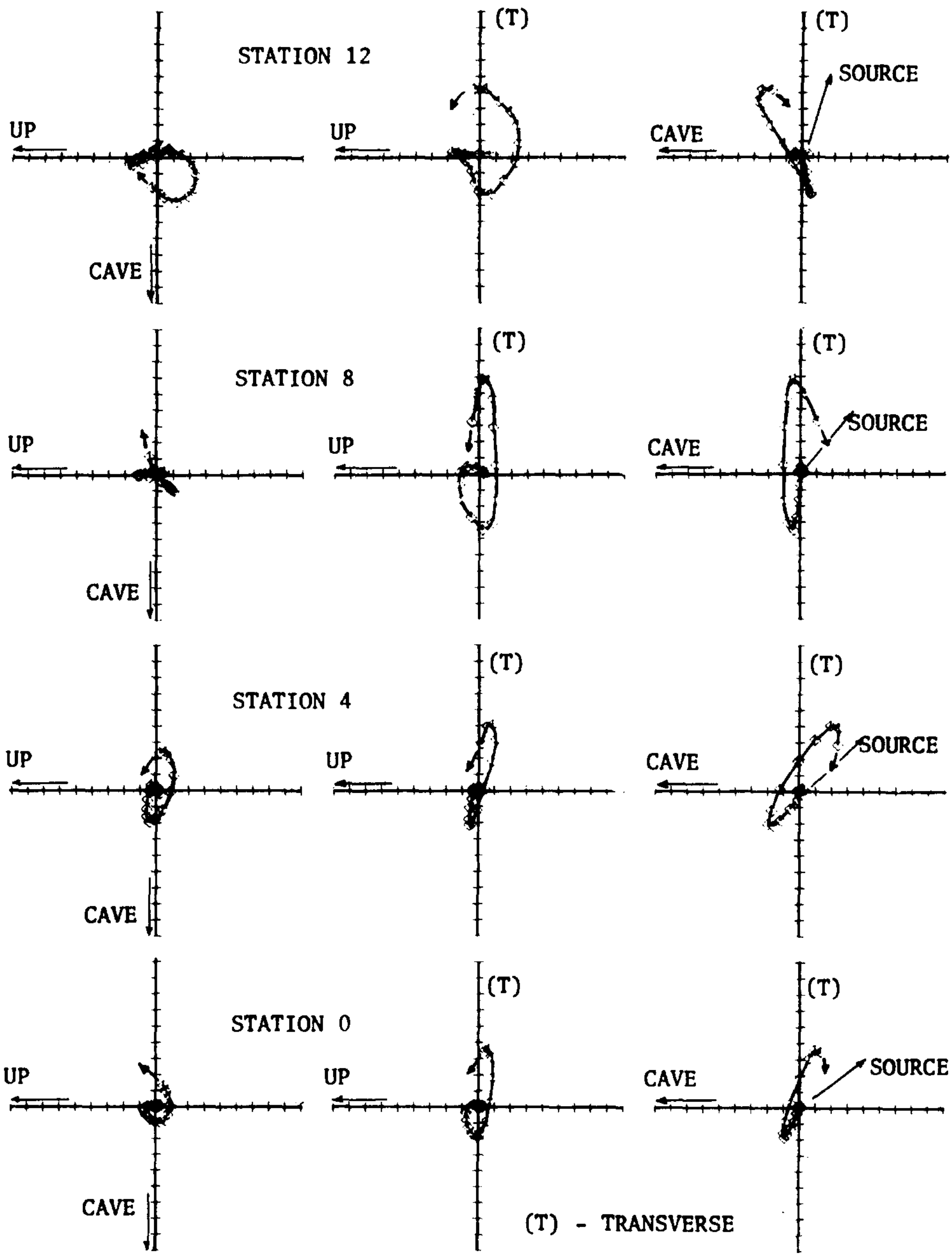

Fig.5. Directional variation of the compressional wave reflection from the cavity roof.

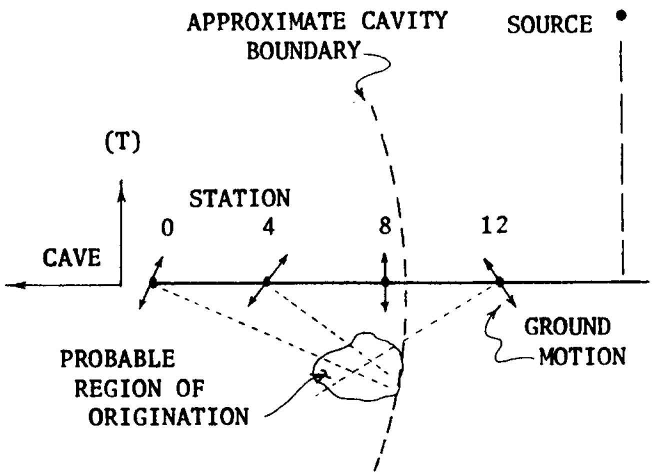

Fig.6. Triangulation of the shear wave reflections from the cavity roof, in plan view.

the cavity. This motion appears to be strictly cavity oriented and occurs only over a limited region of the traverse. In fact, Stations 11 and 12 alone show appreciable energy for this record time. The midpoint between these two stations lies at a polar angle, measured from a vertical axis passing through the center of the Cathedral Room, of approximately 22 degrees.

The event shown in Fig.4h is also an SH-type event but it was not correlatable.

FURTHER EXPERIMENTATION

A limited investigation was conducted on a nearby segment of the same cavern system. This segment is the primary tunnel which leads 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.

For this investigation, the source and detectors were placed on a line perpendicular to the axis of the tunnel. The source was located at a distance of 300 ft. from a point directly over the center of the tunnel, and the detectors were placed at 10-ft. intervals between this point and the source. Due to the remote source location, the recorded signals were extremely weak and led to inadequate data quality. Nonetheless, the measurements show conclusive agreement with the previous investigation.

Fig.7 shows the three-component velocity data for a station located 50 ft. from the point over the center of the cavity. In this figure, the transverse motion is parallel to the axis of the tunnel. Again, significant energy for late record times was observed only over an extremely limited range of the traverse. This region lies at a polar angle of roughlv 28° relative to a vertical axis passing through the center of the tunnel. The motion for these later record times is entirely horizontal and again oriented parallel to the boundary of the void.

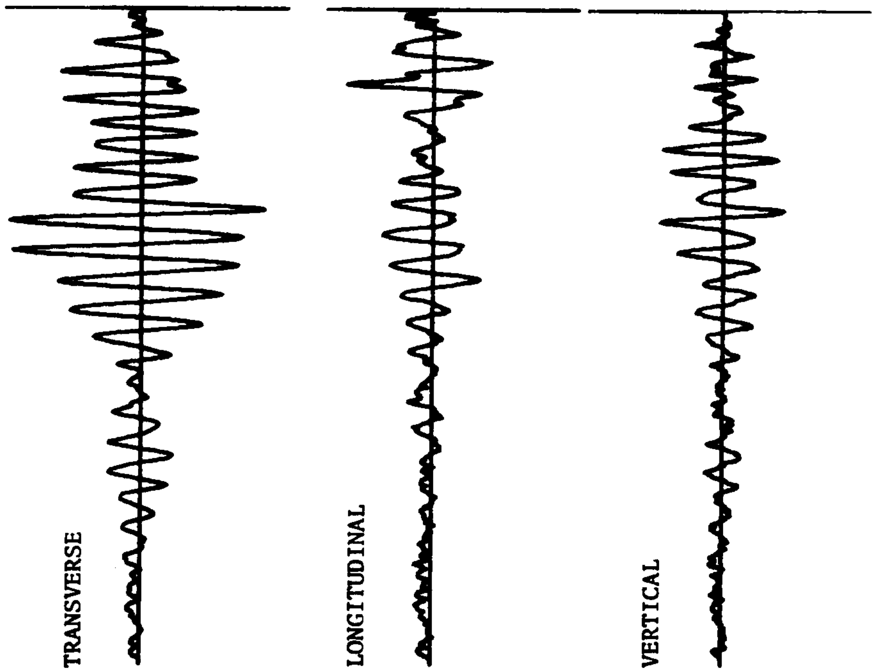

Fig.7. Three-component data for the tunnel investigation. Transverse measurements are parallel to tunnel axis.

DISCUSSION OF RESULTS

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

The ground motions for large record times have the general characteristics of the SH wave type, with the exception that they do not appear to be connected in any way with the source location. Moreover, because they exist only over an extremely limited region of the traverse, it also 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. (1967) and Godson and Watkins (1968). Their conclusions as to the existence of resonance were based upon measurements taken only with vertical seismometers. The results of the current investigation show that the entire vertical record can be explained by travelling waves of the conventional types, with no other event occurring on the vertical trace that would not normally be expected.

The horizontally polarized motion towards the latter 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. The disturbance is definitely cavity oriented. In the event that it is also propagating, the disturbance might possibly be classified as a wave guide effect.

Regardless of the physical nature of the disturbance, it provides a promising diagnostic for the detection and delineation of subterranean cavities.

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