Detecting Voids in a 0.6 m Coal Seam, 7 m Deep, Using Seismic Reflection

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SUMMARY

Surface collapse over abandoned subsurface coal mines continues to be a problem in many parts of the world. High-resolution P-wave reflection seismology was successfully used to evaluate the risk of an active sinkhole to a main north/south railroad line in an undermined area of southeastern Kansas. The water-filled cavities responsible for the sinkholes in this area are in a 0.6-m coal seam 7 m deep. A dominant frequency of 200 Hz was attained enabling us to discern the top of the coal seam from the direct wave, refractions, air wave, and ground roll. Drilling confirmed the geologic interpretation derived from the seismic data. The seismic survey showed that the apparent active sinkhole was not the result of reactivated subsidence but probably erosion.

INTRODUCTION

Detection of subsurface cavities by methods other than drilling is of interest to geologists, hydrologists, and engineers in many parts of the world. Recent advances in high-resolution reflection seismology are applicable to shallow cavity detection (Hunter et al., 1984; Branham and Steeples, 1986; Steeples and Miller, 1987, Steeples and Miller, 1988). Recorded energy with dominant frequencies greater than 100 Hz is needed to detect most small, shallow targets using P-wave reflection seismology. These higher-than-normal frequencies can be attained using nonstandard seismic sources and severe low-cut analog filtering (Miller et al., 1986; Birkelo et al., 1987; Myers et al., 1987). The extreme contrasts of elastic properties between a void (water- or air-filled) and the surrounding rocks should provide an excellent reflection interface.

Gradual subsidence of sinkholes is common in heavily undermined areas of southeast Kansas. The gradual collapse of near-surface material into voids commonly less than 5 m in diameter in the 7-10-m-deep and 0.6-1-m-thick Weir-Pittsburg coal generally results in sinkholes less than 3 m in diameter and with less than 0.3-m of surface depression. Most of these voids are remnants of the "room and pillar" mining method commonly used in this area.

The accelerated rate of subsidence of a previously dormant sinkhole within 20 m of a set of main-line railroad tracks near Scammon, Kansas, represented a potential risk to rail traffic. An approximately four-fold increase in the surface area of this sinkhole, predominantly in the direction of the railroad tracks over a period of two months indicated possible reactivation. To insure the structural integrity and therefore the safety of the tracks, it was necessary to precisely locate the mine shaft responsible for the sinkhole.

GEOLOGICAL SETTING AND FIELD PROCEDURES

The Weir-Pittsburg coal bed has an average thickness of 1 m in southeastern Kansas. It is located within the lower portion of the Cabaniss Formation, which is part of the Pennsylvanian Cherokee Group. The various phases of the Cherokee cyclothems are best interpreted as facies of alluvial-deltaic complexes, the repetitive nature being due to delta shifting and distributary abandonment (Heckel et al., 1979). The Cherokee coals are the culmination of aggrading sedimentation of delta plains. The Weir-Pittsburg coal bed was extensively mined until about 1940 by both subsurface and strip-mining methods. As a result of the subsurface mining, large areas of southeastern Kansas are underlain by a maze of interconnecting cavities.

A seismic survey was designed to maximize the potential for locating horizontal shafts that might cross beneath the north/south railroad tracks (Fig. 1). Two preliminary lines were collected to determine the optimum acquisition parameters. Two production lines were then acquired parallel to the tracks on opposite sides of the tracks and centered on the active sinkhole. The acquisition parameters used on the two production lines were designed to allow direct detection of any subsurface void present beneath the seismic lines. Confident correlation between the two production seismic lines is possible if the trend and size of horizontal shafts that cross beneath the tracks are relatively consistent.

The data were collected using a standard CDP acquisition method. The source-and-receiver spacing was 0.6 m. The source was a downhole .30-06 single-shot rifle with its barrel 0.1 m below the ground surface in a 3-cm borehole. The receivers were 2-100 Hz geophones on 14 cm spikes connected in series with a 0.3 m in-line spacing. Maximum recordable reflection frequencies were maintained partly as a result of the careful attention to source-and-receiver couple throughout acquisition.

The data were recorded on an I/O DHR-2400 seismograph. The fixed-gain data were converted analog-to-digital (A/D) into an 11-bit plus sign value and then stored on magnetic tape in modified SEG-Y format. The recording system amplifiers have 72 dB of dynamic range with a 120 nanovolt RMS noise level. The anti-alias filters used have a 60-dB/octave roll-off with a -60-dB point of 2000 Hz. A pre-A/D low-cut filter with a 24 dB/octave roll-off and a -3 dB point of 340 Hz was used to maximize resolution and reduce the effects of ground roll. The selected low-cut filters were essential to the quality and success of this survey.

DATA PROCESSING

The data were processed on a Data General MV-20,000 computer (using basic CDP seismic processing techniques). Special emphasis was placed on defining and applying a digital bandpass filter to optimize the spectral difference between voids and intact coal. The primary processing procedures performed on the seismic data were NMO correction and digital filtering.

RESULTS

Reflections from the coal seam can be interpreted from raw field-files (Fig. 2). The coal reflector has a unique curvature and frequency spectrum that separates it from the refracted-wave, direct-wave, and air-wave energy. The reflection energy has a dominant frequency in excess of 200 Hz. The two-way arrival time of the coal reflection is consistent with the uphole survey. The reflection energy returning from the void lacks trace-to-trace coherency and consistency in frequency content. The optimum recording window (Hunter et al., 1984) and parameters (Knapp and Steeples, 1986) were selected from walkaway tests with source-to-receiver spacing ranging from 0.3 m to 37 m on 0.3 m intervals and low-cut filters of 240 Hz, 340 Hz, and 480 Hz.

The voids can be separated from competent coal according to frequency, amplitude, coherency, and seismic character on the 12-fold CDP stack of line 3 (Fig. 3). The first three positive amplitude arrivals between 10 msec and about 22 msec are refractions. The refractions were not muted in order to avoid disturbing the reflected arrival that closely trails the refractions as evidenced on the field file (Fig. 2). The difference in the seismic characteristics of voids in the coal and intact coal are obvious when the drill-confirmed voids around CDP 250 and 290 are compared to the drill-confirmed coal at CDP 270. The coal reflector at CDP 270 is higher amplitude, more coherent, and lower frequency than the reflection energy of the bounding voids. The geologic interpretation is based on information acquired through drilling, seismic reflections, and uphole velocities. The correlation of the drill information and the seismically derived interpretation of line 3 justifies confidence in the overall interpretation (Fig. 4).

The sinkhole's migration path toward the railroad tracks does not correlate to any tunnel location interpreted from seismic data (Fig. 4). Voids on the north half of line 4 were extrapolated beneath the tracks and correlated to voids on the north half of line 3 according to seismic character, void size, and spacing of the "room and pillar" grid patterns. Three tunnels can then be inferred to cross beneath the tracks linking CDP location 210 on line 3 with 230 on line 4, 244 on line 3 with 265 on line 4, and 290 on line 3 with 310 on line 4. The surface location and migration path of the sinkhole suggests a tunnel should be oriented northeast/southwest beneath CDP location 310 on line 3 and CDP location 340 on line 4. There is no indication on the seismic sections of a void at either of those locations. The mechanism responsible for the accelerated growth rate of the sinkhole is apparently not related to subsidence.

Surface investigation revealed a correlation between the migration path of the sinkhole walls and the local drainage pattern of surface water. The original formation of the sinkhole probably was from surface collapse of material surrounding a vertical shaft. The recent reactivation of the expansion of the perimeter of the sinkhole is predominantly along a topographic low that is acting as a channel for surface-water runoff. The erosion associated with the water flow has elongated the sinkhole along the drainage channel. Absence of water in the sinkhole indicates surface water is probably escaping through the reopened vertical shaft. The accelerated rate of subsidence and growth direction of the sinkhole should remain consistent with the amount and drainage pattern of surface-water runoff in the immediate area.

CONCLUSION

High-resolution seismic reflection methods were successfully used to evaluate the risk to rail traffic of an active sinkhole within 20 m of the tracks. Voids were interpreted on the seismic sections and then correlated between the two seismic lines acquired on opposite sides of the tracks. Three tunnels were confidently interpreted to cross beneath the tracks. Drill data and uphole survey agreed with the seismic-reflection data on depth-to-coal, location of intact coal, location of voids in the coal seam, and two-way travel time from the surface to the coal and back to the surface. The areal expansion of the sinkhole was determined from seismic data not to be related to the collapse of a horizontal mine shaft. The accelerated growth is probably a result of erosion.

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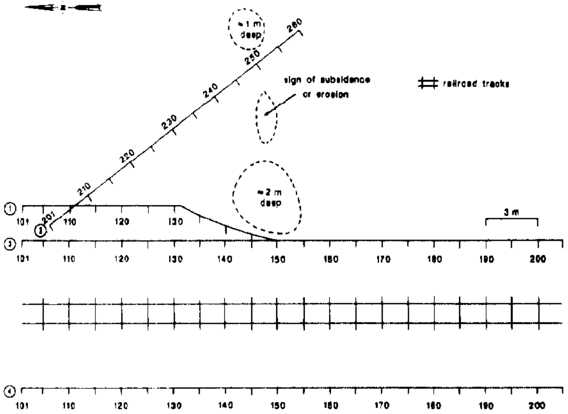

FIG. 1. Map view of seismic lines with respect to the tracks.

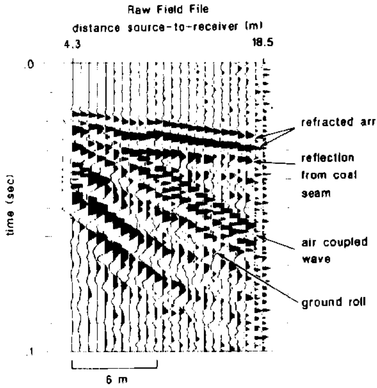

FIG. 2. Field file showing reflection from coal.

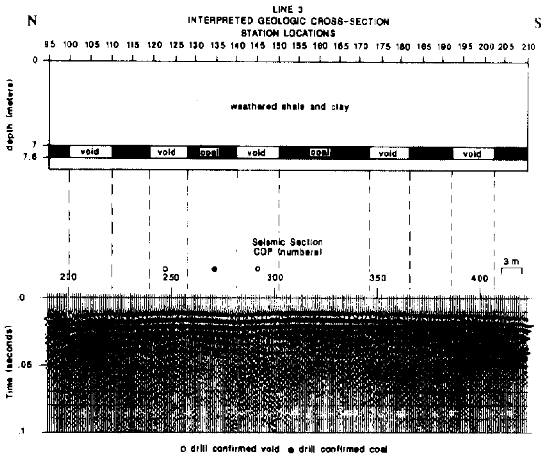

FIG. 3. Line 3, 12-fold CDP stack and geologic interpretation.

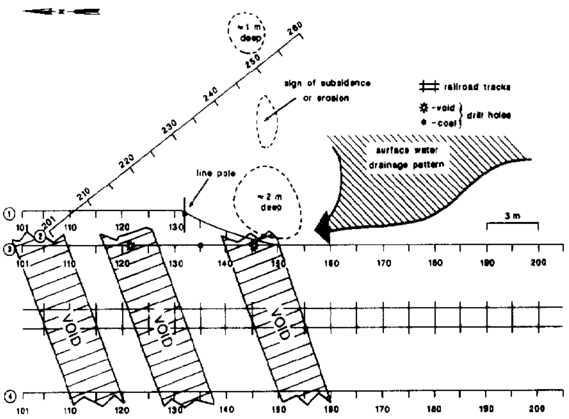

FIG. 4. Interpreted tunnel locations from seismic data.