Diffraction imaging versus reflection processing for shallow void detection

Shelby L. Peterie and Richard D. Miller, Kansas Geological Survey, Don W. Steeples, University of Kansas*

Summary

Voids were imaged with greater detail using a diffraction imaging technique than with traditional seismic reflection processing. Subsurface voids in extensively mined areas pose a threat to human life and property. Seismic reflection techniques applied to the void detection problem have had limited success. Data acquired in July of 1985 over a former coal mine were originally processed with standard reflection processing techniques. These data were reprocessed using a diffraction enhancement algorithm to image corners of voids using diffracted waves. Results from diffraction imaging are consistent with the reflection processing results and other information from the site, and image additional voids that were not initially detected using the reflection approach.

Introduction

A diffraction occurs when the seismic wavefront encounters a subsurface discontinuity that is much smaller than the seismic wavelength (Yilmaz, 2001). Examples of such discontinuities include faults, pinch outs, and other abrupt terminations of a reflector. These features are can be detected on common-midpoint (CMP) stacked seismic sections using standard seismic reflection processing techniques (Landa and Keydar, 1998). However, interpretation of these relatively small objects is difficult due to the resolution limits of compressional wave (P-wave) reflections. Shallow void detection is a particularly difficult problem for traditional seismic reflection methods. At best, approximate void locations can be estimated from CMP stacked sections as areas where reflectors are less coherent and have anomalous amplitudes and dominant frequency (Miller and Steeples, 1988; Branham and Steeples, 1998; Miller and Steeples, 1995).

Diffracted P-waves have potential to image details smaller than the resolution limits of reflections due to their distinctly different raypaths (Neidell, 1997; Kaidukov et al, 2004). Exact void locations can be determined from diffraction imaging results as a large amplitude anomaly on the trace recorded by the receiver directly above the void and depth can be calculated from the arrival time (Walters et al., 2009). The essential assumption of the algorithm is that every subsurface point potentially contains a scattering object, and data are processed to enhance each potential diffraction.

This study compares CMP reflection processing results to diffraction imaging results. Data for this case study were acquired at the site of a former coal mine. Data were initially processed using traditional CMP reflection processing methods. The same data were reprocessed using the diffraction imaging algorithm developed by Walters et al. (2009). Results from both processing methods are compared and evaluated based on drilling information and other studies at the site.

Geologic Setting and Acquisition Parameters

Data were acquired in July of 1985 at the Pittsburg Industrial Park in southeastern, Kansas. The target of the study was the Weir-Pittsburg coal bed, a member of the Pennsylvanian age Cherokee group. The 1-1.5 m thick coal bed (Zeller, 1968) is overlain by approximately 10 m of mostly shale, sandstone and sandy shale (Branham and Steeples, 1988). Coal was extracted from this site from the late 1800s to mid-1900s using “room and pillar” style mining. Pillars of coal were left between mined rooms to preserve structural integrity and avoid collapse of overlying layers.

Homes, businesses, and other structures have been built on top of old mines in this area due to poor documentation of void locations. Over time these voids have caused the formation of numerous sinkholes that endanger both property and human life. A shallow seismic survey was designed to detect void locations and evaluate structural integrity.

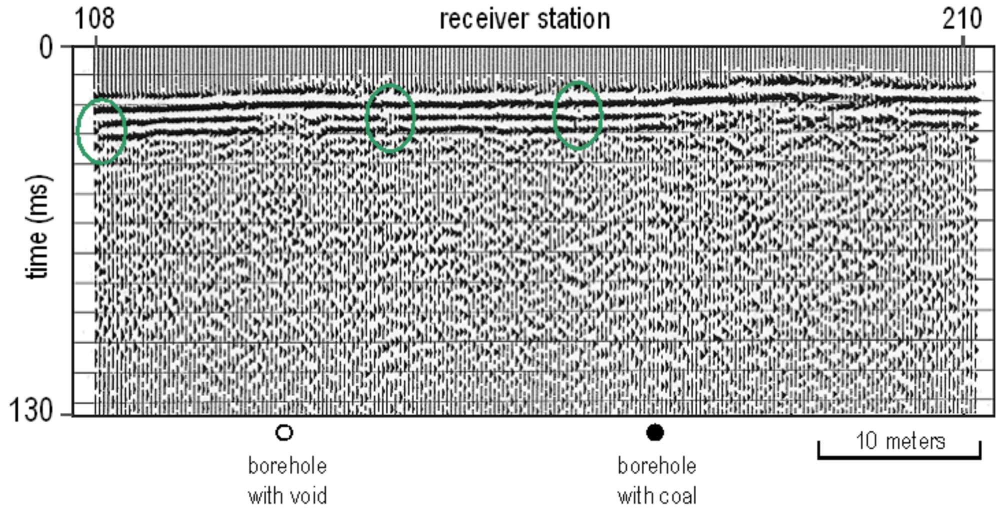
One line of data was acquired in a roll-along style survey with a modified .30-06 caliber rifle. Receivers were single 100 Hz spiked geophones spaced at 0.5 m intervals. The location of the seismic line was selected so that receivers crossed from an area of flat topography into an area with surface expression of subsidence. An uphole survey was conducted in an existing borehole near the line to establish the two-way traveltime for the top of the coal.

Method 1: CMP Reflection Processing

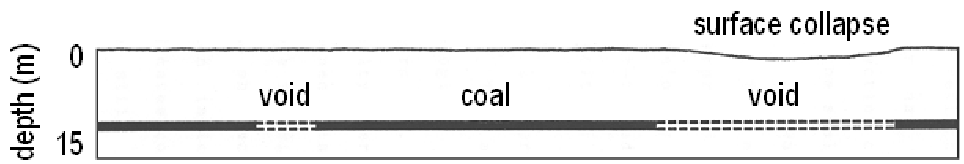
The seismic reflection data were originally processed using the CMP approach. Processing steps included trace editing, static correction, NMO correction, CMP stacking, filtering, and scaling. The first arrivals were not muted to preserve shallow reflections from the top of the coal bed.

The high amplitude event between 15 to 22 ms on the stacked section is a result of coherently stacked first arrival energy (Figure 1a). A strong reflector between 23 to 25 ms on the stacked seismic section was confirmed by the uphole survey to be the top of the coal seam. Lower amplitude,

(a)



(b)



(c)

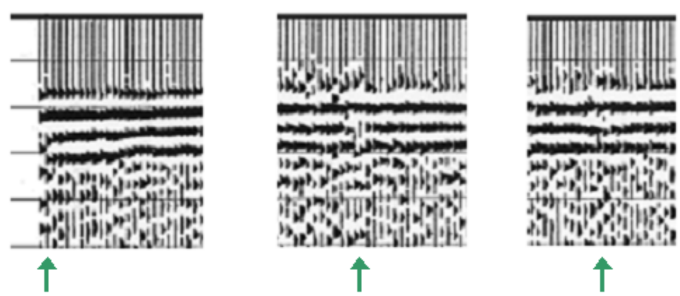


Figure 1: (a) Seismic profile and (b) interpreted cross-section resulting from standard CMP processing. Green circles in (a) indicate subtle discontinuities in the reflection from the top of the coal that are not associated with the interpreted voids. (c) Close-ups of the discontinuities in (a) indicated with an arrow. Modified from Branham and Steeples (1988).

less coherent areas of the reflector between receiver stations 127 to 132 and 175 to 202 were interpreted as voids in the coal bed (Figure 1b). The surrounding areas of the reflector that are more coherent and higher in amplitude were interpreted as competent coal.

Two boreholes were drilled to evaluate this interpretation. A borehole drilled at station 130 intersected a void in the coal bed, and a borehole drilled at 173 intersected competent coal. These observations support the original interpretation of the CMP stacked section.

Method 2: Diffraction Processing

The seismic reflection data were reprocessed using the diffraction imaging technique outlined by Walters et al. (2009). The diffraction enhancement algorithm was performed on field records to enhance potential diffraction apexes and attenuate noise and other wavefield components. The velocity for diffraction moveout correction derived from direct and refracted waves is consistent with NMO velocities determined during CMP processing. Enhanced shot gathers were re-sorted into common receiver gathers. Diffraction apex enhancement was performed on receiver gathers, resulting in a two-dimensional (2-D) profile indicating lateral location and two-way zero-offset traveltime of scattering objects (Figure 2a).

Diffractions likely occur at the corners of each room and pillar and, therefore, each pair of diffractions indicates a void. Four voids are interpreted between stations 98 to 109, 123 to 135, 146 to 162, 179 to 208. Stations 98 and 208 are uncertain due to low fold. This interpretation, like the interpretation of the CMP stacked section, is supported by the information from boreholes drilled at stations 130 and 173.

Discussion

The seismic profiles resulting from CMP processing and diffraction imaging are both consistent with the surface expression of subsidence and drilling information. Though the diffraction profile indicates the presence of a greater number of voids, this interpretation is consistent with the CMP stacked section. The two voids centered near stations 130 and 188 are positioned at approximately the same locations with each method.

There are three subtle discontinuities in the reflection from the top of the coal that are not associated with interpreted voids at stations 109, 144, and 162 on the CMP stacked section (Figure 1a). On the diffraction profile these stations are associated with the corners of voids. The regular, alternating areas of coal and void are consistent with the "room and pillar" mining technique that was used in the area where the data were acquired.

The partially-imaged void between stations 98 to 109 on the diffraction profile is likely not imaged in the CMP stacked section due to poor midpoint coverage in this low-fold area. One possible reason the void from stations 147 to 162 appears to be a nearly continuous reflector on the stacked section is that subsidence above a void likely contributes to discontinuity of the underlying reflector. The reflector may appear more continuous if there was no subsidence above this particular void.

Conclusion

The interpretation of diffraction imaging results is consistent with the interpretations of the CMP stacked section and with drilling and other information from this site. Both methods identified two voids at the same locations. The diffraction enhancement method imaged the corners of two additional voids that can only be identified on the CMP stacked section as subtle discontinuities in the reflection from the top of the coal. The diffraction profile imaged voids with greater detail than the CMP stacked section due to the inherent resolution potential of diffractions.

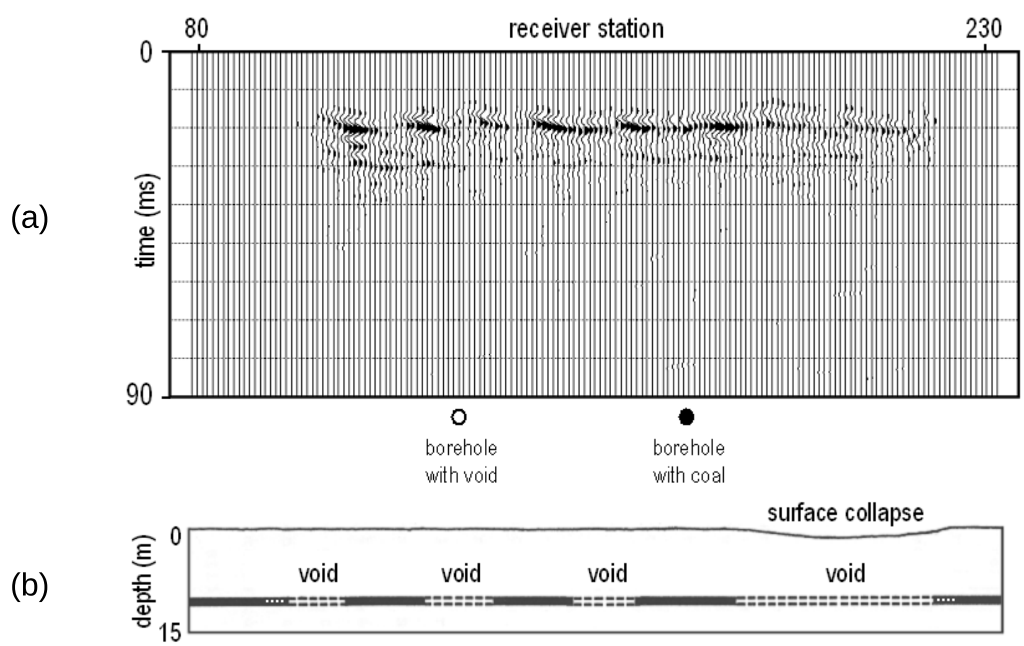


Figure 2: (a) Seismic profile and (b) interpreted cross-section resulting from the diffraction imaging algorithm.

EDITED REFERENCES

Note: This reference list is a copy-edited version of the reference list submitted by the author. Reference lists for the 2009 SEG Technical Program Expanded Abstracts have been copy edited so that references provided with the online metadata for each paper will achieve a high degree of linking to cited sources that appear on the Web.

REFERENCES

Branham, K. L. and D. W. Steeples, 1988, Cavity detection using high-resolution seismic reflection methods: Mining Engineering, **40**, 115-119.

Kaidukov, V., E. Landa and T. J. Moser, 2004, Diffraction imaging by focusing-defocusing: An outlook on seismic superresolution: Geophysics, **69**, 1478-1490.

Landa, E. and S. Keydar, 1998, Seismic monitoring of diffraction images for detection of local heterogeneities: Geophysics, **63**, 1093-1100.

Miller, R. D. and D. W. Steeples, 1995, Applications of shallow, high-resolution seismic reflection to various mining operations: Mining Engineering, **47**, 355-361.

Miller, R. D. and D. W. Steeples, 1988, Tunnel detection by high-resolution seismic methods: Presented at the Third Technical Symposium on Tunnel Detection.

Neidell, N. S., 1997, Perceptions in seismic imaging Part 2: Reflective and diffractive contributions to seismic imaging: The Leading Edge, **16**, 1121-1123.

Walters, S. L., R. D. Miller, D. W. Steeples, J. Xia, J. Ivanov, C. Zeng, 2009, Detecting tunnels and underground facilities using diffracted P-waves: 22nd Annual Meeting, Symposium on the Application of Geophysics to Engineering and Environmental Problems, Expanded Abstracts, 937-942.

Yilmaz, O., 2001, Seismic data analysis: Processing, inversion, and interpretation of seismic Data: SEG.

Zeller, P. E., 1968, The stratigraphic succession in Kansas: Kansas Geological Survey, Bulletin 189.