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Modeling of seismic wave propagation around coal mine roadway with presence of excavation-damaged zone

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Motivation and Research Outline

In-seam seismic methods have been widely used in underground coal mine exploitation since early 80's. They are helpful for identification of stress concentration zones or to locate geological disturbances within the coal seam. Usually, such surveys are optimized to perform seismic tomography. Therefore, sources and receivers are located on the opposite sides of the longwall. Results are produced in form of velocity maps of body-waves for rock-coal-rock medium or maps of group velocity and frequency of Airy-phase of dispersive waves trapped inside the coal seam, so-called channel waves (Evison, 1955; Krey, 1963). However, with the above geometry, the high-resolution imaging of the rock mass close to the roadway, including excavation-damaged zone (EDZ), is hampered by the available ray coverage. In order to overcome this limitation, sources and receivers should be mounted in the same roadway. There is also a fundamental problem contributing to the lack of a robust method to image such area, which is the complexity of the seismic wavefield in the vicinity of the roadway. In a coal seam, where both surface tunnel waves and Rayleigh and Love-type channel waves overlap.

We address this problem using numerical simulations. We use finite-difference method and viscoelastic model with petrophysical parameters for coal and host rock layers representative for the Upper Silesia mining district. First, we analyze seismic waves propagation within simple rock-coal-rock model (**model #1**), particularly channel waves dispersion properties. Then, we add a roadway (**model #2**) and 3-meter thick EDZ (**model #3**) to the model. Velocity and density within the EDZ linearly decrease up to 70% close to the free surface of excavation. Eventually, we insert 10% Gaussian-shape velocity anomaly with 20 m width in the middle of the roadway to the model (**model #4**) and investigate changes in frequency and group velocity of Airy-phase of Love-type channel waves for different offsets.

Method

We use staggered-grid finite-difference method (Bohlen, 2002) and SOFI3D open-source modelling code to simulate the wave propagation in the vicinity of the roadway with presence of EDZ. To examine the influence of a roadway to wave propagation we compute theoretical dispersion curves for Love channel wave based on phase recursion algorithm (Rader et al., 1985, Shott and Waclawik, 2015). The Rayleigh-type channel wave theoretical dispersion curves are determined according to Yang et al. (2014). For Rayleigh and Love surface wave we use Geopsy software (Wathelet, 2008).

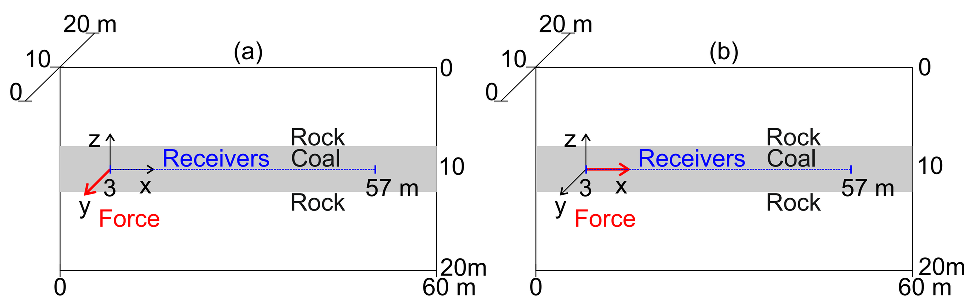
Physical parameters

	Thickness (m)	P-wave (m/s)	S-wave (m/s)	Density (kg/m3)	Q factor (P-wave)	Q-factor (S-wave)
Host rock (upper half-space)		4500	2600	2600	350	140
Coal seam	2	2400	1400	1400	150	60
Host rock (lower half-space)		4500	2600	2600	350	140
Roadway	5	0	0.0001	1250	10e10	10e10

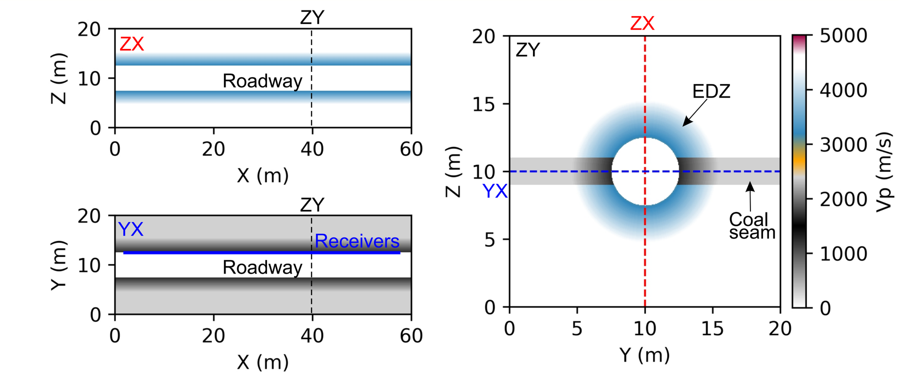
Modelling parameters

Model type	visco-elastic
Grid spacing	0.05 m
Model size	20 x 20 x 60 m
Source	250 Hz and 370 Hz normal to sidewall
Receivers	in the center of coal seam
Source shape	sin-wave

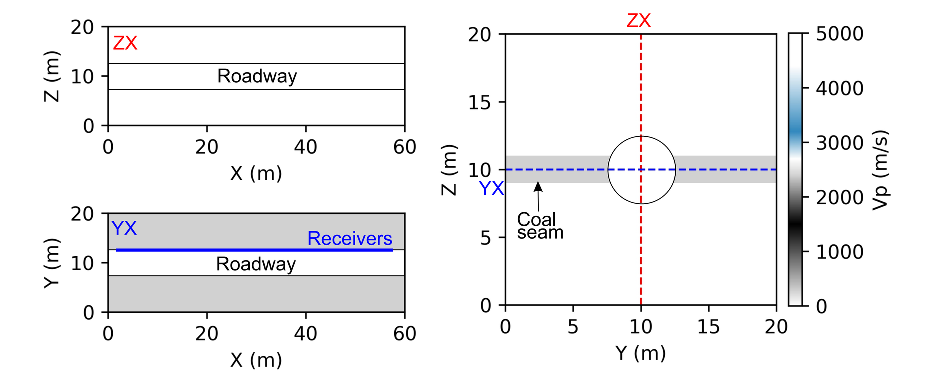
Undisturbed coal seam / MODEL #1



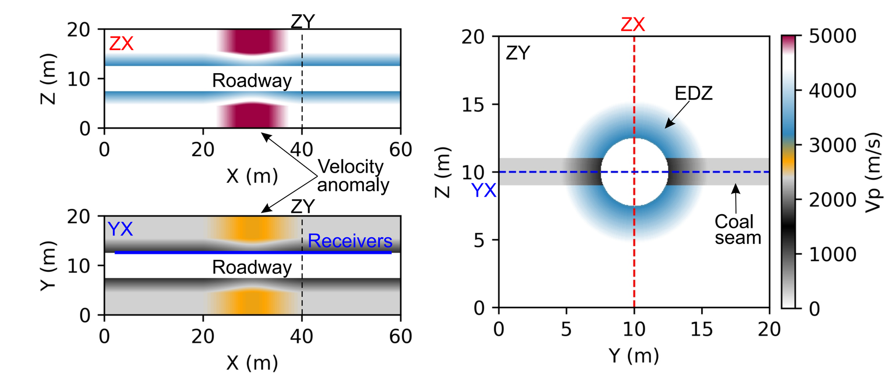
EDZ / MODEL #3



Roadway / MODEL #2

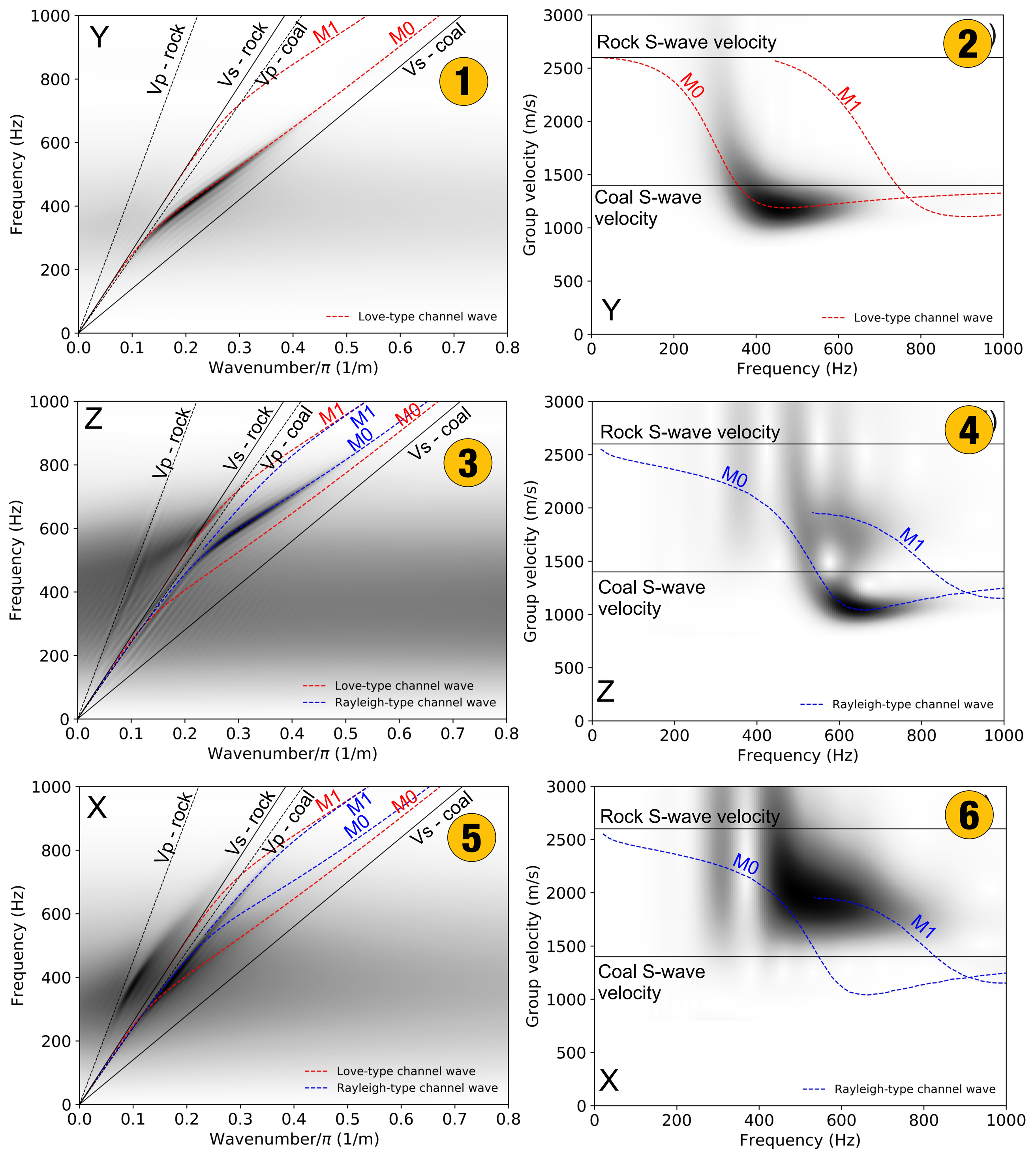


EDZ + 10% anomaly / MODEL #4



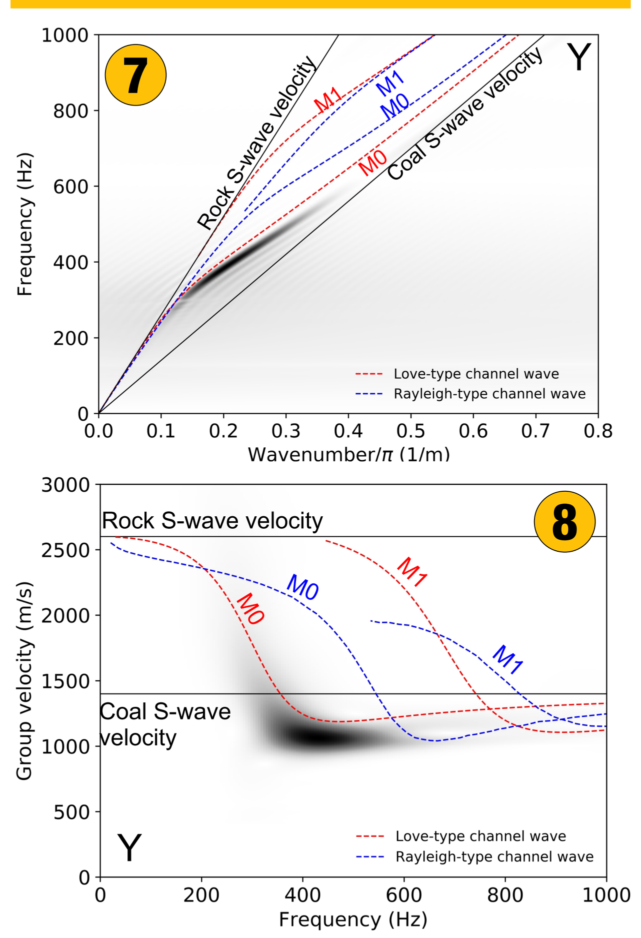
Results

MODEL #1

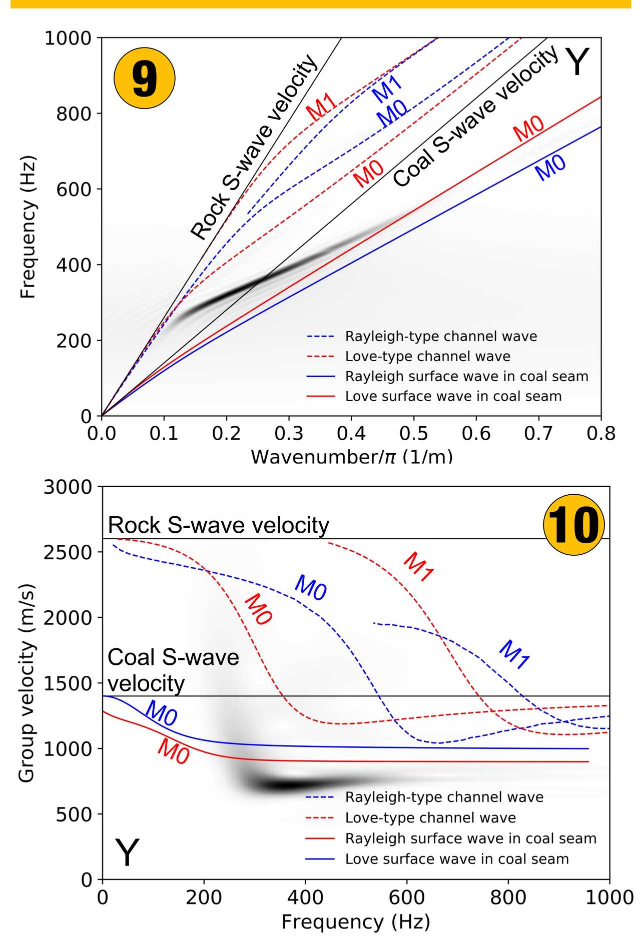


Results

MODEL #2



MODEL #3



MODEL #4

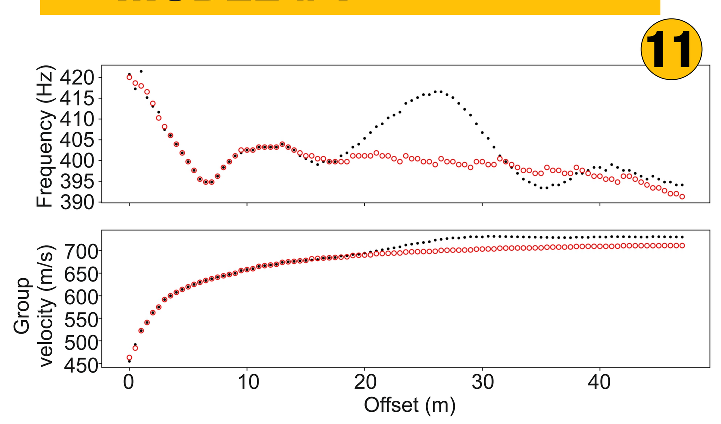


Fig. 11.The changes of frequency and velocity of wave group with maximum energy for single shot for model #3 (red dot) and model #4 (black dot)

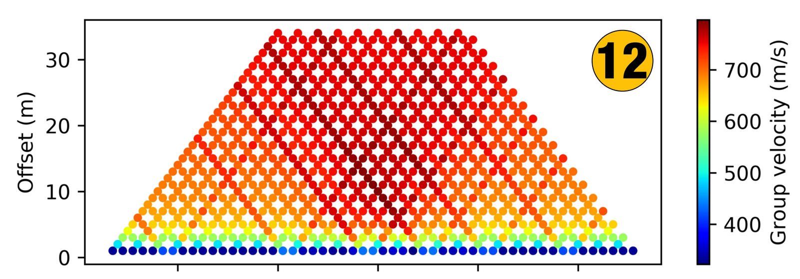


Fig. 12. Group velocity changes of wave group with maximum energy for muliple shots along the geophone array for model #4

Discussion and Conclusions

The results confirm dispersive nature of the seismic waves propagation inside the coal seam. We analyze short geophone array up to 54 m. We observe weak influence of intrinsic attenuation for such distance for channel waves. We illuminate the area around Airy phases for fundamental mode of Love-type channel wave (1) (2) and Rayleigh-type channel wave (3) (4) (5) (6) by excitation the source with central frequencies around them. The Love-type channel wave dominates for horizontal component perpendicular to the travel path (1) (2). The Rayleigh-type channel wave emerges on vertical (perpendicular to the roof/floor of seam layer) (3) (4) and horizontal (parallel to the travel path) (5) (6). However, in the center of the seam the fundamental mode is observed only on vertical component (3) (4). The symmetrical and antisymmetrical behavior of channel wave displacement is well known (Dresen and Ruter, 1994). In the presence of roadway (**model #2**), the so-called roadway mode is observed (Lagasse and Mason, 1975, Essen et al. 2007, Krajewski et al., 1987). Such mode has similar shape to Love-type channel wave fundamental mode but about 10% lower velocity (7) (8). It was also observed numerically in Lagasse and Mason (1975) and empirically in Krajewski et al. (1987). Interesting is that minimum group velocity (Airy phase) corresponds with minimum of that for Rayleigh-type channel wave fundamental mode (8). In case of EDZ we notice lower velocity for minimum wave group (9) (10). Interesting is that such minimum is even smaller than the minimum velocity for Rayleigh and Love surface wave for coal layer and EDZ ((10), red and blue solid lines). For short wavelength the wave travels as a fundamental mode of Rayleigh surface (tunnel) wave (9). By use of the fact that dominant energy for short distance is focused around Airy phase (even absorption is applied), we are able to detect group velocity and frequency variation within EDZ (11) (12). The changes of these parameters reflect the changes in the medium and can be linked to the rock mass deformation. Future research should involve inversion of frequency-dependent seismic waves around a roadway to obtain S-wave velocity profile of the EDZ.

Acknowledgments

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Refereces

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