13th International Conference on
Structural Health Monitoring of Intelligent Infrastructure
DOI: 10.3217/978-3-99161-057-1-011

Rail track subsurface imaging from train vibrations recorded at dark fiber networks

Michael Behm[1], Michael Brauner[2]

[1]GEODATA ZT GmbH, Hans-Kudlich-Straße 28, 8700 Leoben, Austria
[2]ÖBB-Infrastruktur AG, Lassallestraße 5, 1020 Wien, Austria
email: michael.behm@geodata.com, michael.brauner@oebb.at

ABSTRACT: We demonstrate the practical feasibility of assessing geotechnical parameters of rail infrastructure based on 'dark fiber' distributed acoustic sensing (DAS) recordings using trains as sources. A workflow to image the shallow (3 m – 20 m depth) subsurface in terms of shear wave velocity has been established. The shear wave velocity distribution is obtained from inversion of seismic surface waves excited by the trains and recorded on the fiber optic cables, and is used as a proxy for the geotechnical strength (e.g., shear modulus). Our results allow for the interpretation of potential geologic hazards and other features relevant for assessing the geotechnical integrity of rail infrastructure. This approach does not require dedicated field measurements or interruption of the train schedule, and therefore represents a cost-effective and robust method for different application scenarios.

KEY WORDS: DAS, hazard, infrastructure, rail, near-surface geophysics

1 INTRODUCTION

Shallow geologic hazards such as washouts, karstification, liquefaction, or mass movements pose risks to rail infrastructure and operations. Additionally, the stability of artificial rail embankments may be affected by poor consolidation or external influences such as extreme weather events or neo-tectonic activity. While the conventional near-surface geophysical toolbox provides a range of suitable investigation methodologies, their application to rail networks is challenged by the train operation schedule and the potentially large spatial extent.

In recent years, Distributed Acoustic Sensing (DAS) performed on existing fiberoptic cable infrastructure ('dark fiber') has become a widely used approach for seismic subsurface imaging and monitoring (Li et al, 2022). As many rail tracks are equipped with fiberoptics for telecommunication purposes, and trains are sources of abundant seismic energy, the method is potentially well suited for seismic subsurface imaging below rail tracks (Hernandez et al., 2023; Fuchs et al, 2018).

We present a case study from Austria (Europe), where DAS registrations of commuter trains along a 6.5 km long rail track section were used to image the shallow subsurface. A workflow comprising data selection, seismic interferometry, and advanced MASW (multi-channel analyses of surface waves) techniques resulted in almost continuous coverage of the shear wave velocity (Vs) in the depth interval ~3 m - ~20 m. The results were validated against conventional MASW data and existing geologic/geotechnical information.

2 METHOD

DAS measurements provide strain or strain rate variations along a fiberoptic cable with potentially high resolution and accuracy. Dynamic strain variations are an expression of dynamic medium deformations, and therefore DAS data can be considered as first-order proxies to seismic wavefields. Seismic processing techniques can be used to model and characterize the subsurface in terms of shear wave velocity (Vs) distribution which is indicative of geotechnical properties (e.g., shear modulus). Our workflow starts with geometrical calibration of the DAS recordings and selection of recording periods which include trains. In a next step, the seismic interferometry method (e.g., Wapenaar et al., 2010, and references therein) is applied to reconstruct surface Rayleigh waves propagating in-between individual DAS channels and is used to synthesize virtual shot gathers for each channel. Those shot gathers are subjected to a proprietary MASW workflow Xia et al., 1999) with emphasis on improving the S/N (signal-to-noise) ratio and taking advantage of the dense spatial sampling capabilities of DAS (Guan et al., 2024). The final output is a continuous 2D-model of the shear wave velocity distribution Vs below the rail tracks.

3 DATA, PROCESSING, AND RESULTS

The used fiber optic cable is installed in a hard-plastic protective tubing which runs inside a large concrete duct, therefore poor ground coupling is to be expected. Several loops and partial re-routing of the cable required careful geometrical calibration. A Febus A1 interrogator (Febus, 2025) was used for the measurement. Aiming for compromise between resolution and S/N ratio, the gauge length and channel spacing were chosen as 2 m and 0.8 m, respectively, such that finally 8,751 channels were recorded along the 6.5 km long section. The total recording length cumulates to ~7 h, during which time 29 commuter trains were registered with a temporal sampling rate of 2 ms, resulting in a data volume of ca. 370 GB. The trains are short (3 – 6 carriages) and operate with low speed (~70 km/h). From the continuous recordings, we only use short time windows around the train arrivals which contribute to ca. 5% of the entire data set.

The MASW workflow aims at deriving Vs-depth profiles at a nominal spacing of 5 m which are interpolated into continuous 2D models (Fig 1). The average frequency range for the retrieved surface waves is ~7 Hz - ~16 Hz. Due to partially insufficient fiber-ground coupling and re-routing, 70% of the section could be imaged continuously (Fig. 1). The resulting Vs-models were verified against conventional active source MASW profiles, geological and borehole information, and CPT logs. Overall, those different methods support the results obtained from the seismic imaging workflow.

The results allow for the interpretation of weakened embankment zones and shallow potential geologic hazards. A suspected small-scale mass movement is indicated by

DOI: 10.3217/978-3-99161-057-1-011

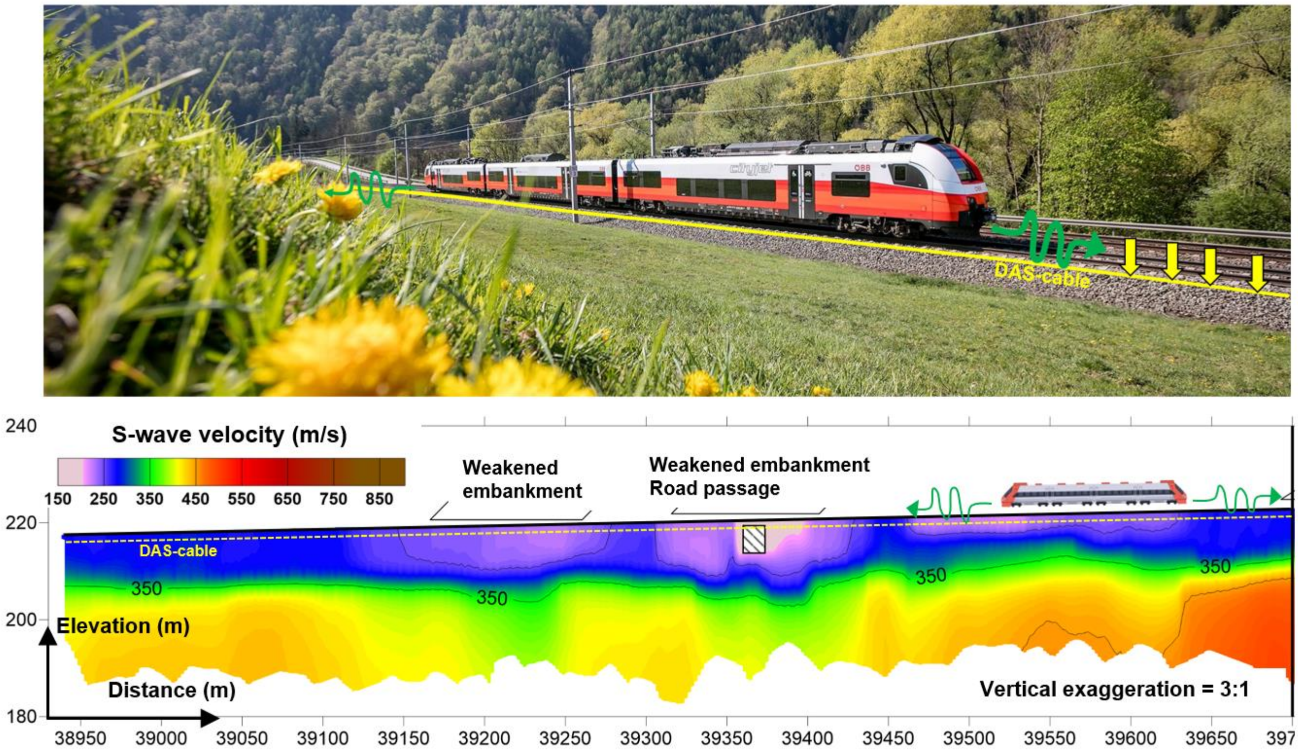

Figure 1: Concept and result of the seismic processing workflow applied to DAS-data. Passing trains excite seismic surface waves (green wiggles), which are recorded at existing fiberoptic telecommunication cables (yellow line). The recorded seismic waves are inverted for the shear-wave (S-wave) velocity structure below the fiberoptic cable. Zones of low S-wave velocity (pale/purple colors) are interpreted for reduced shear strength and thus reduced geotechnical integrity (e.g., weakened embankments). Velocity variations at larger depths are indicative of lithological inhomogeneities.

significantly decreased velocities, and a known large-scale fault zone with the potential for neo-tectonic reactivation correlates with low velocities at larger depths.

4 CONCLUSIONS

We have developed an efficient and robust workflow for imaging potential geologic hazards along rail tracks from seismic waves excited by trains and recorded on existing fiber infrastructure. This approach does not require dedicated field measurements or interruption of the train schedule. It can be used for large-scale mapping of entire rail networks as well as for time-lapse monitoring of selected and potentially hazardous sections. The methodology might also be applied to roads using vehicle noise as seismic sources.

ACKNOWLEDGMENTS

We thank Martin Litzenberger from the Austrian Institute of Technology (AIT) for supporting the DAS-measurement.

REFERENCES

Febus, 2025: Febus A1 data sheet. Accessed through https://www.febus-optics.com/en/page/a1, August 2025

Fuchs, F, G. Bokelmann, and AlpArray Working Group, 2018, Equidistant Spectral Lines in Train Vibrations, Seismological Research Letters, **89**, 56-66

Guan, J., Cheng, F., Xia, J., Mi, B., Sun, H., and Ajo-Franklin, J.B., 2024, Multigrid Spatially Constrained Dispersion Curve Inversion for Distributed Acoustic Sensing (DAS), iEEE Transactions on Geoscience and Remote Sensing, **62**, 1-17

Hernandez, E.O, P. Hölscher, P. Doornenbal, C. Mas, J. van‘t Schip, and A. van Uitert, 2023, Characterization of Shallow Ground in Railway Embankments Using Surface Waves Measured by Dark Fiber Optics Sensors: A Case Study, Sensors, **23**, 9397

Li, Y., M. Karrenbach, and J.B. Ajo-Franklin (Eds.), 2022, Distributed Acoustic Sensing in Geophysics, AGU Geophysical Monograph Series 268, Wiley

Wapenaar K., Draganov D., Snieder R., Campman X., and Verdel A., 2010, Tutorial on seismic interferometry: Part 1 – Basic principles and applications, Geophysics 75, 75A195–75A209.

Xia, J., Miller, R.D., and Park, C.B., 1999, Estimation of near-surface shear-wave velocity by inversion of Rayleigh waves, Geophysics, **64**(3,) 691–700