Bahrain workshop asks “What are we getting?” from FWI

Husam AlMustafa¹ and Tariq A. Alkhalifah²

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In response to popular demand and positive feedback from previous events, a third SEG workshop about full-waveform inversion (FWI) was organized and convened 4–6 December 2017 in Manama, Bahrain. The theme was “Full-waveform inversion: What are we getting?” The objective of the workshop was to assess the potential of FWI while comparing outputs and results, taking into account challenges and difficulties. Special emphasis was placed on challenges related to high resolution and reservoir attributes, waveform inversion of microseismic events, and the ever-challenging salt body.

The workshop attracted a diverse group of attendees. There were 65 participants from 13 countries and 23 companies/institutions. Contributors represented the following: Saudi Aramco, Kuwait Oil Company (KOC), Schlumberger, CGG, Shell, Petroleum Geo-Services, King Abdullah University of Science and Technology (KAUST), University of Western Ontario, National University of Singapore, University de Grenoble, Seoul National University, Petroleum Institute, Institute of Petroleum Geology and Geophysics, École Nationale Supérieure des Mines de Paris, Institut de Physique de Globe de Paris, University of Science and Technology of China, Tongji University, ETH Zurich, Delft University of Technology, University of Western Australia, and Woodside Energy Ltd.

The workshop took place at the Sofitel hotel, which hosted an engaging exchange of knowledge in FWI experiences and a beautiful sunset at the end of the day, as this resort was located along the gulf on the west shore of Bahrain. The gala evening event on the second day allowed participants to share in social activities and enjoy a nice dinner at the hotel.

Keynote addresses included:

- Opening by Mustafa Ali, Saudi Aramco
- Gerhard Pratt, University of Western Ontario
- Constantine Tsingas, Saudi Aramco
- Jean Virieux, University de Grenoble
- Harve Chauris, École Nationale Supérieure des Mines de Paris
- Andreas Fichtner, ETH Zurich
- Tariq Alkhalifah, KAUST

Highlights of technical sessions

Session 1: Acquisition and preprocessing for FWI

- A novel approach to predicting low-frequency information for FWI was presented.

- The session discussed the implementation of the reflection inversion method with a source extension function to handle the cycle-skipping problem of early arrivals and reflections.
- A new workflow for FWI was introduced to address the field data problem.

Session 2: Onshore and offshore case studies

- In a land example, the envelope was used for the low frequencies in FWI.
- In a marine example, an enhanced image in reverse time migration was obtained using FWI velocity.
- Successful FWI can produce a reliable high-resolution near-surface velocity update, even with a very noisy data set.
- To improve FWI results, we need (1) acoustic approximation; (2) diving, postcritical, and reflected waves; and (3) anisotropy by joint reflection and refraction tomography.
- Acoustic FWI has become a standard tool in marine seismic processing, but there are problems associated with it.
- In FWI, surface waves have to be attenuated at each iteration.
- Short-offset and high-frequency data can be used to retrieve the shallow variation in the velocity model.
- Long-offset and low-frequency data can be used to retrieve the deep variation in the velocity model.

Session 3: Multiparameter

- The value of multicomponent data and other acquisition geometries (e.g., vertical seismic profiling) for multiparameter FWI was examined.
- More work is needed to establish links between the output of FWI (data-fitting method) and geologic parameters. FWI alone will not be sufficient.
- The session examined the trade-off between parameters solved through two approaches.

Session 4: Extended FWI/image-based FWI

- There is always the assumption that there is a gap in the wavenumbers of the model obtained from the data. However, there is debate about whether this gap is real or if it is a problem created from our workflow. Hence, is there a way to decrease the gap by modifying our current workflow?
- Positive results have been observed, especially when subsurface extension is considered. Should we continue in this direction?

¹Saudi Aramco, Dhahran, Saudi Arabia. E-mail: husam.mustafa@aramco.com.

²King Abdullah University of Science and Technology, Thuwal, Saudi Arabia. E-mail: tariq.alkhalifah@kaust.edu.sa.

- There is visible crosstalk between the parameters, especially for P- and S-wave perturbations. Can we continue exploring this problem in the physics of the elastic subsurface?
- There is a lingering question regarding the wavenumber content in the background model. How can we link the wavenumber content in both the delta M and the background model, and how can we continue to relate it with frequencies of the data?
- Is it necessary to assume a scale separation between the background model and the perturbation?

Session 5: Time lapse and passive data inversion

- A localized waveform inversion for time-lapse surveys can enhance image quality while reducing the computational cost.
- A high-resolution time-lapse velocity change estimator allows us to infer time-varying fluid migration and interaction with the reservoir during injection. The time lapse is robust and can estimate small velocity changes even when events are not perfectly repeated or contain nonrepeatable noise.
- Simulation with synthetic viscoacoustic data encourages the use of time-lapse seismic imaging of the Q factor for reservoir monitoring.
- A new approach to noise interferometry was presented that fully accounts for the heterogeneous and time-variable distribution of noise sources and correctly incorporates any type of linear and nonlinear processing. In addition, it allows for any type of medium, including viscoelastic and anisotropic media.

Session 6: Near-surface FWI

- A joint traveltime, waveform, and waveform envelope inversion method recovers both low wavenumbers (from envelope) and high wavenumbers.
- Envelope inversions retrieve low frequencies.
- The session discussed the use of cascaded FWI steps of consecutive frequencies in the Laplace Fourier domain to invert for the shear-wave velocity model from a relatively simple starting model. The advantage of the method lies in its

computational efficiency (as compared to the conventional time-domain FWI).

Session 7: Constraints in FWI

- FWI with optimal constraints is required to improve the delineation of salt-body and subsalt structures. Total variation regularization, Cauchy function, and hinge-loss function constraints may have promising features.
- Wavelet-based multiscale FWI and double-difference wavefield tomography have been proposed in the seismology community.

Session 8: Software/computer aspect

- A comprehensive introduction to a high-performance software package designed to solve large-scale, full-waveform inverse problems was presented. This package covers the complete tool-chain of time-domain waveform inversion with modules for numerical wave propagation, meshing, inversion, and workflow management.
- FWI based on cloud computing requires the FWI code to improve scalability and data security.

Conclusion

The workshop provided a forum for technical exchange on many subjects affecting the course of FWI. Richness in the variety of sessions set the stage for informative presentations and constructive dialogue. In terms of seismic data, a wealth of discussions revolved around the topic of spatial and frequency content.

Looking to mitigate the effect of cycle-skipping and local minima, several topics were addressed. The topics included attributes such as traveltimes, phase, envelope, integration, data crosscorrelation, and the Laplace, Fourier, and wavelet transforms. Misfit design was also a central area of interest. Topics reviewed methods of comparing observed data to synthetic data with standard least-squares misfit, but also with L1 norm comparison, or optimal transport nonlocal comparison. In addition, one of the key points was the importance of choosing the right physics that will honor the data and inevitably drive the model parameter reconstruction. Several points in the area of model construction

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were also communicated. Examples included parameters that are important in achieving a better fit to seismic data when there are high contrasts; P-wave and S-wave complexity; anisotropy; and attenuation, which also alters seismic amplitudes. It was also shown that data-driven FWI is an effective and efficient way of velocity model building. To close the loop, it's important to keep in mind the validity of the images obtained from FWI, and hence, uncertainty quantification is a crucial step in the FWI process.

Looking back at the previous two workshops, it is evident that the topics covered in this workshop tackled several issues that were raised in earlier workshops. We also have witnessed how an increased number of oil companies are adopting FWI as a tool for imaging their complex challenges. We are confident that the future of FWI is bright and will open doors to opportunities thought to be previously closed.

Technical Committee

The Technical Committee included: Husam AlMustafa (chairman), Saudi Aramco; Tariq A. Alkhalifah (cochairman), KAUST; Mohammad Jassem, KOC; Ahmad Riza Ghazali,

Petronas; Ali Almomin, Saudi Aramco; Kwangjin Yoon, Saudi Aramco; Riyadh Al-Saad, Saudi Aramco; Gerhard Pratt, University of Western Ontario; Aldo Vesnaver, Khalifa University of Science and Technology; Denes Vigh, Schlumberger; Herve Chauris, MINES ParisTech; Jiubing Cheng, Tongji University; Anatoly Baumstein, ExxonMobil; Giles Lambare, CGG; Paul Williamson, Total; Li Peiming, BGP; Maarten de Hoop, Rice University; Rene Plessix, Shell; and Togrul Konuk, Petronas.

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