Poro-viscoelastic simulation and its application for seismic CO_2 monitoring in the Gandhar oilfield, India

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In recent years, much attention has been drawn by the possibility of CO_2 sequestration into geological formations which can help achieve the net-zero CO_2. However, post-CO_2-injection, it is also required to monitor the reservoir to avoid any risk of CO_2 leakage. This is where the seismic method becomes very helpful as it can monitor a large area with appreciable accuracy. However, the question remains as to how early we can detect the leakage through seismic signature. This is dependent on several factors ranging from the geological settings to rock/fluid properties. In this work, we attempt to perform a full wavefield seismic simulation to obtain the seismic signatures in the given a geological scenarios.

For this study, we have selected the Gandhar oilfield that is located in the Cambay Basin of western India. Recent research studies, including source-sink matching, petrophysical properties analysis, current reservoir and minimum miscibility pressure (MMP) analysis, and other laboratory research studies have recommended the Gandhar oilfield as a viable candidate for the implementation of the CO_2 EOR technique (Mishra et al., 2019). ONGC has planned to inject the CO_2 in the Hazad sands to recover an extra 15% of residual oil equivalent to 20 million barrels of crude oil to strengthen India's energy security. Regarding the reservoir, the major pay formation belongs to Hazad sands (GS-1 to GS-12) of the Ankleshwar Formation. Over the years, approximately 40% of the original oil in place has been extracted from these multi-stratigraphic pay sands by primary and secondary recovery production. Given above, it is a perfect candidate for testing theory as the learning from simulation can be directly transferred.

The seismic response of a porous medium filled with pores can be simulated considering the two-phase material (i.e., acoustic/elastic solid and fluid) as a continuum to account for the influence of pore fluids on the seismic properties of rocks (Biot, 1956). However, the predicted attenuation levels are significantly lower than those observed practically (Mochizuki, 1982) for which viscoelasticity can be incorporated into Biot's model using squirt-flow (Carcione, 2008) which is a key attenuation mechanism resulting from matrix-fluid interaction. This poro-viscoelastic model can be used for numerical simulation. In particular, we have used the finite difference method, which requires lower memory, and computational resources as compared to other numerical approaches. However, seismic wave simulations in such media remain computationally expensive due to the additional variables involved in their formulation. To further improve the efficiency we have used the vectorized derivative operator (Malkoti et al., 2018). In summary, we have implemented a finite-difference numerical scheme with vectorized spatial derivative operator with an 4th-order accuracy over the staggered-grid and 2nd-order accurate time derivative method. The SGFD operators are reformulated by shifting the center of the approximation, enabling simultaneous updates across the entire domain and significantly increasing computation speed.

The proposed method is employed to the Gandhar oil field, Cambay Basin, India where we assumed that CO_2 is injected in the Hazad Sand (Figure 1). The parameters were selected to avoid any numerical instability and grid dispersion. The source was assumed as a point source, located at a depth of 40 meters from the top with a Ricker wavelet signature. We have carried out the simulation for two different scenarios- 1) Pre-injection, where model had no CO_2, and 2) Post-injection, where the Hazad layer had 30% CO_2 saturation. Seismograms (vertical component of particle velocity) recorded for each scenario are compared in the Figure 1.

The poro-viscoelastic seismograms for the pre- and post-CO2 injection scenarios show the differences in amplitude due to CO_2 saturation. This is obvious, since poroviscoelastic model have higher attenuation due to squirt flow, when compared to the poroelastic model. The same work is useful for obtaining the seismic response in presence of CO_2, depending on its saturation. This has a direct implication on reservoir monitoring during injection and detecting CO_2 leakage.

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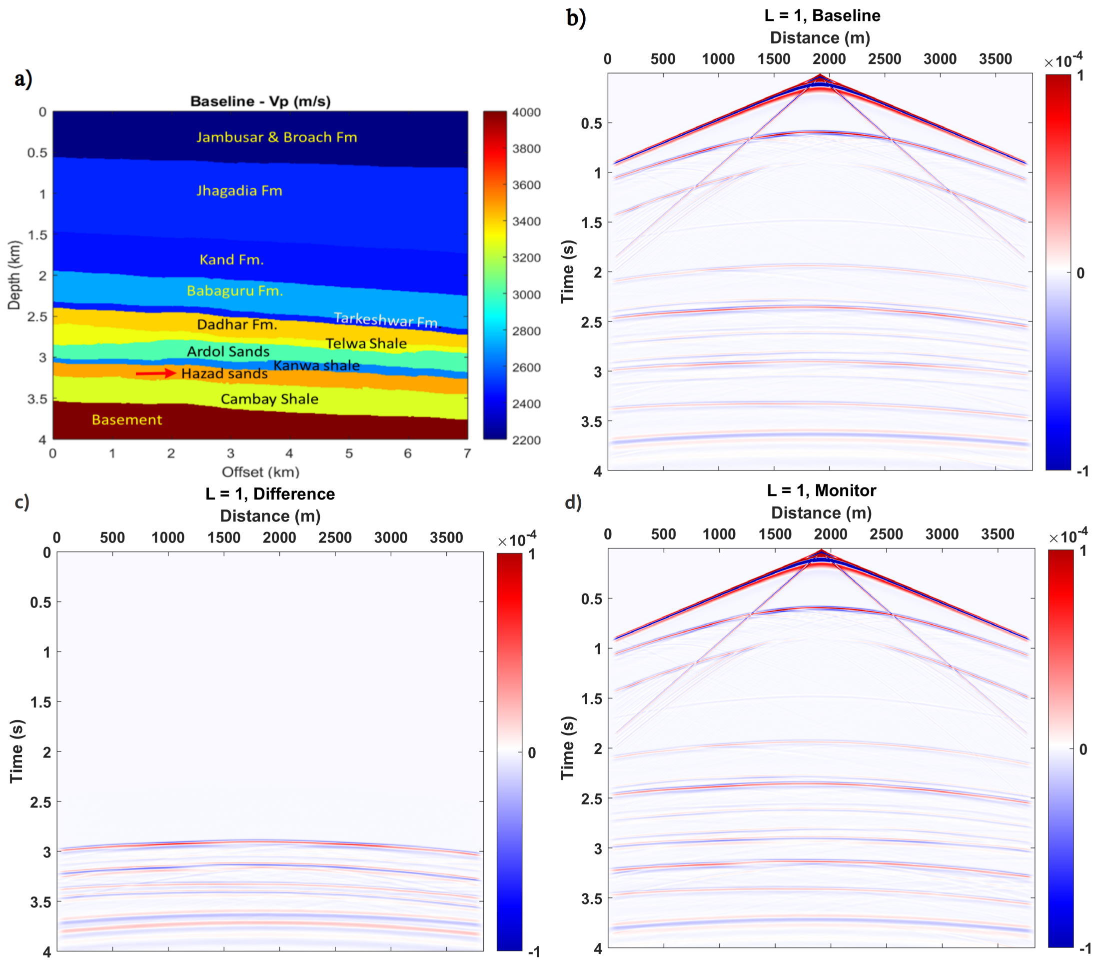

Figure 1: (a) Gandhar V_p model with different layers where CO_2 was injection is assumed for Hazad layer. (b, d) represent the results obtained after poro-viscoelastic seismic simulation. c) represents the difference the Monitor and Baseline data.

References

Biot, M. A. (1956). Theory of propagation of elastic waves in a fluid-saturated porous solid. ii. higher frequency range. *The Journal of the acoustical Society of america*, 28(2):179–191.

Carcione, J. M. (2008). Viscoelastic effective rheologies for modelling wave propagation in porous media. *Geophysical prospecting*, 46(3):249–270.

Malkoti, A., Vedanti, N., and Tiwari, R. K. (2018). An algorithm for fast elastic wave simulation using a vectorized finite difference operator. *Computers & Geosciences*, 116:23–31.

Mochizuki, S. (1982). Attenuation in partially saturated rocks. *Journal of Geophysical Research: Solid Earth*, 87(B10):8598–8604.