A first-order qSV-wave propagator in 2D VTI media

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Abstract

In this study, we propose a first-order qSV-wave propagator in general 2D vertical transversely isotropic (VTI) media, which can be easily employed with staggered-grid finite difference scheme. By further correction of projection deviation of simulated wavefield components, residual qP-waves will be completely eliminated and separated scalar pseudo-pure-qSV-mode waves can be obtained. We have performed the algorithm to several VTI models, the synthetic results demonstrate the validity and feasibility of this algorithm. In addition, the more efficient first-order Hybrid-PML can be directly implemented in this algorithm with good performance.

Theory and Method

First, we project the original elastic wavefields onto isotropic references through the introduction of a similarity transformation to Christoffel matrix. In this way, equivalent Christoffel equation of qSV-waves is derived and through inverse Fourier transform, second-order pseudo-pure-qSV-mode wave equations can be obtained (Cheng and Kang, 2016). Second, we introduce velocity fields v_x and v_z as intermediate variables and keeps the same relationship between displacement fields and velocity fields as they are in original elastic wave equations. Then, we further introduce variables: σ_{xx}, σ_{zz}, σ_{xz}, σ_{zx} and obtain the first-order qSV-wave equations (Liu, et al., 2018):

$$
\begin{aligned}
\rho\frac{\partial\sigma_{xx}}{\partial t} &= C_{11}\frac{\partial\, v_x}{\partial x}\\
\rho\frac{\partial\sigma_{zz}}{\partial t} &= C_{33}\frac{\partial\, v_z}{\partial z}\\
\rho\frac{\partial\sigma_{xz}}{\partial t} &= C_{44}\frac{\partial\, v_x}{\partial z} - (C_{13}+C_{44})\frac{\partial\, v_z}{\partial z}\\
\rho\frac{\partial\sigma_{zx}}{\partial t} &= C_{44}\frac{\partial\, v_z}{\partial x} - (C_{13}+C_{44})\frac{\partial\, v_x}{\partial x}\\
\rho\frac{\partial\, v_x}{\partial t} &= \frac{\partial\, \sigma_{xx}}{\partial x} + \frac{\partial\, \sigma_{xz}}{\partial z}\\
\rho\frac{\partial\, v_z}{\partial t} &= \frac{\partial\, \sigma_{zx}}{\partial x} + \frac{\partial\, \sigma_{zz}}{\partial z}
\end{aligned}
\qquad (1)
$$

By applying spatial domain deviated operators designed by Cheng and Kang (2016), pure scalar qSV-waves will be obtained.

Synthetic Examples

For comparison, in this study we performed the numerical simulation of qSV-wave propagation by both elastic wave equations and first-order pseudo-pure-qSV-mode wave equations proposed in this study.

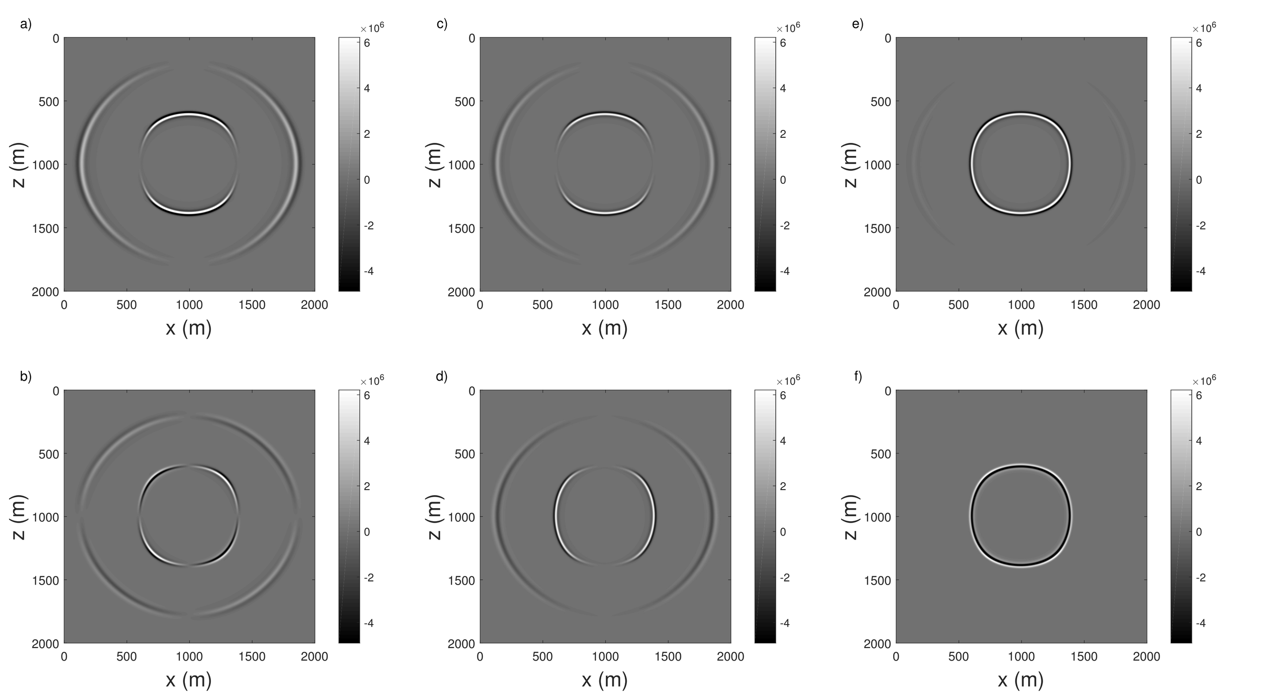

Fig. 1: Synthetic wavefields in a VTI medium with weak anisotropy: a) x- and b) z-component simulated by original elastic wave equations; c) x- and d) z-component simulated by first-order pseudo-pure-mode qSV-wave equations; e) pseudo-pure-mode scalar qSV-wave field; f) separated scalar qSV-wave field.

Synthetic Examples

In the first case, we apply the algorithm to a homogeneous VTI medium with weak anisotropy, whose $vp_0 = 3000m/s$, $vs_0 = 1500m/s$, $\epsilon = 0.1$ and $\delta = 0.05$, a force source is loaded at v_x grid point right in the middle of the model. In the second case, we apply the new algorithm to a VTI medium with strong anisotropy, whose elastic parameters: C_{11} is 23.87 GPa, C_{33} is 15.33 GPa, C_{13} is 9.79 GPa, C_{44} is 2.77 GPa and density is $2500kg/m^3$.

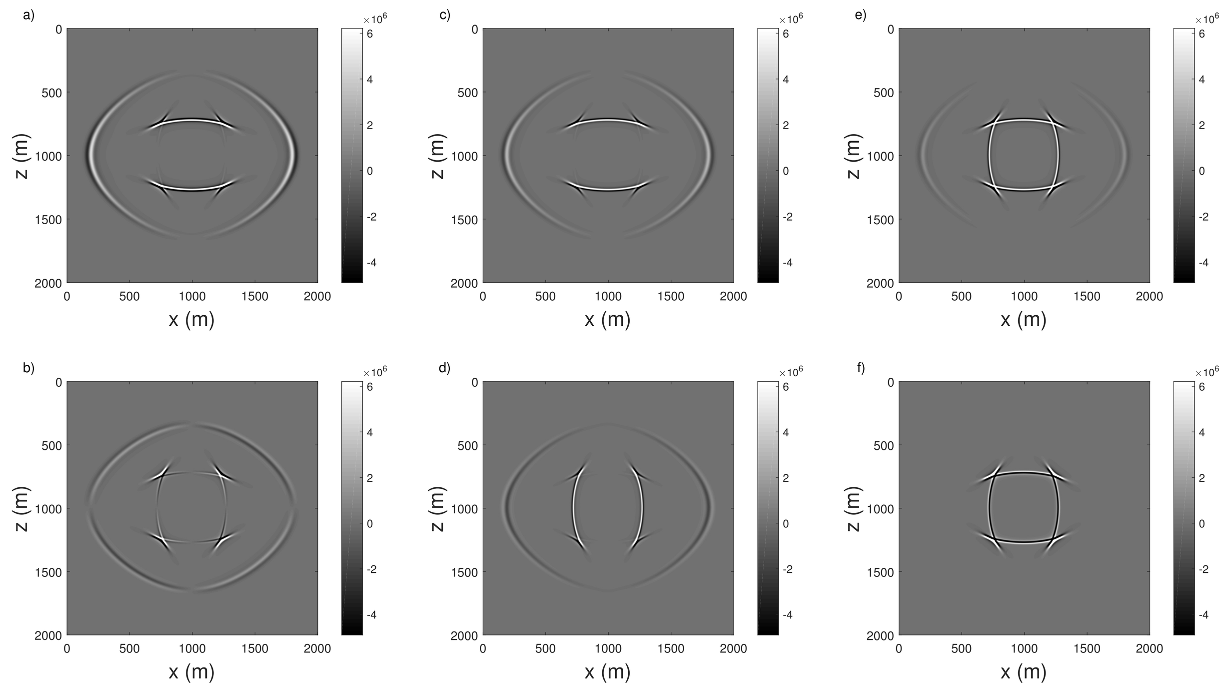

Fig. 2: Synthetic wavefields in a VTI medium with strong anisotropy: a) x- and b) z-component simulated by original elastic wave equations; c) x- and d) z-component simulated by first-order pseudo-pure-mode qSV-wave equations; e) pseudo-pure-mode scalar qSV-wave field; f) separated scalar qSV-wave field.

The snapshots of synthetic qSV-wavefields at different time with Hybrid-PML (Liu, et al., 2017) applied are shown in Figure 3.

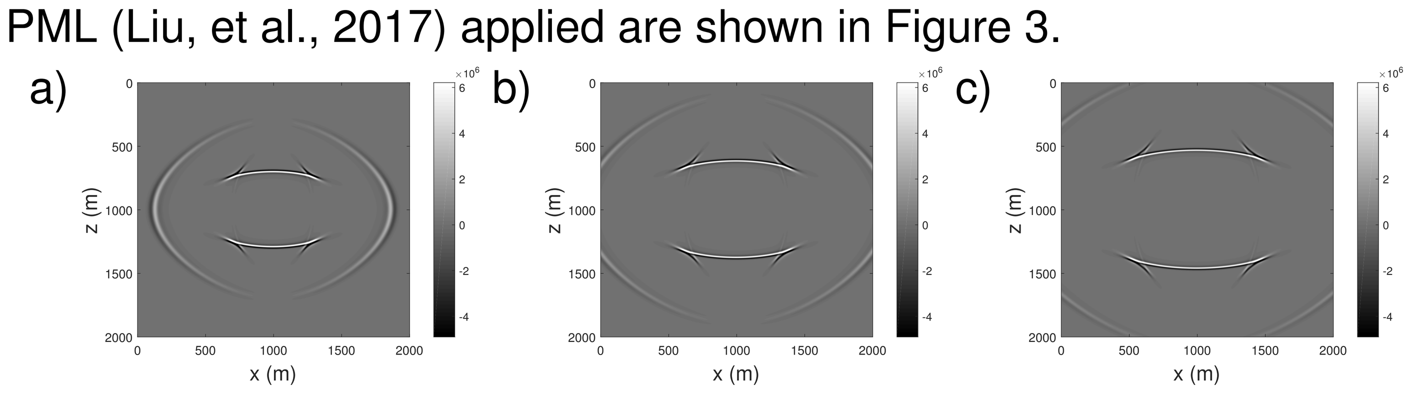

Fig. 3: Snapshots of x-component simulated by first-order pseudo-pure-mode qSV-wave equations in a VTI medium with strong anisotropy: a) 320 ms, b) 400 ms and c) 480 ms, respectively.

In this section, the new algorithm is applied to a heterogeneous layered VTI model, in which the first and the second layer are the same VTI medium with strong and weak anisotropy, respectively.

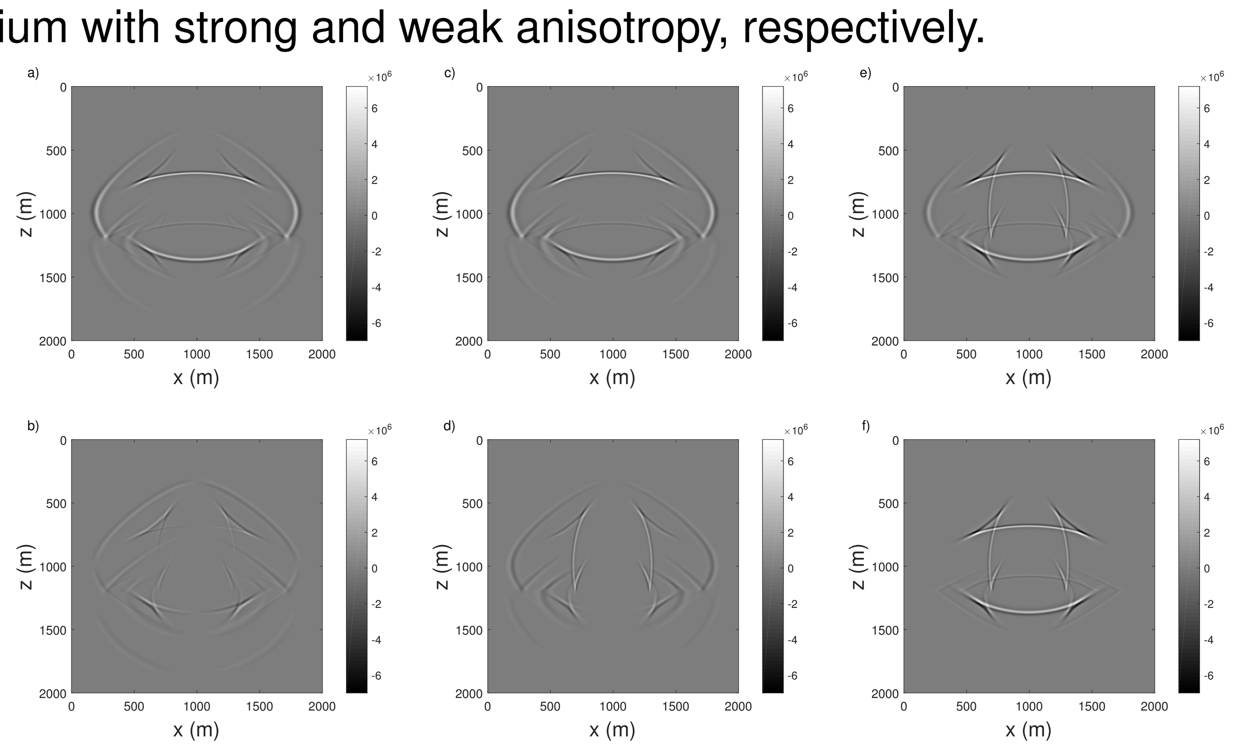

Fig. 4: Synthetic wavefields in a layered VTI model with strong anisotropy in the first layer and weak anisotropy in the second layer: a) x- and b) z-component simulated by original elastic wave equations; c) x- and d) z-component simulated by first-order pseudo-pure-mode qSV-wave equations; e) pseudo-pure-mode scalar qSV-wave field; f) separated scalar qSV-wave field.

It's demonstrated that with further polarization-based correction, not only is qP-wave energy eliminated, but also the converted P-wave energy.

Synthetic Examples

In the final example, we apply the new algorithm to part of the SEG/Hess VTI model. For a heterogeneous model, all spatial domain deviation operators for each medium need to be calculated with their elastic parameters. As shown in Figure 5 are the synthetic qSV-wavefields, from which we can observe that after the summation of x- and z- components, qP-mode wave energy has already been extremely suppressed. With further correction, separated scalar qSV-mode waves are obtained .

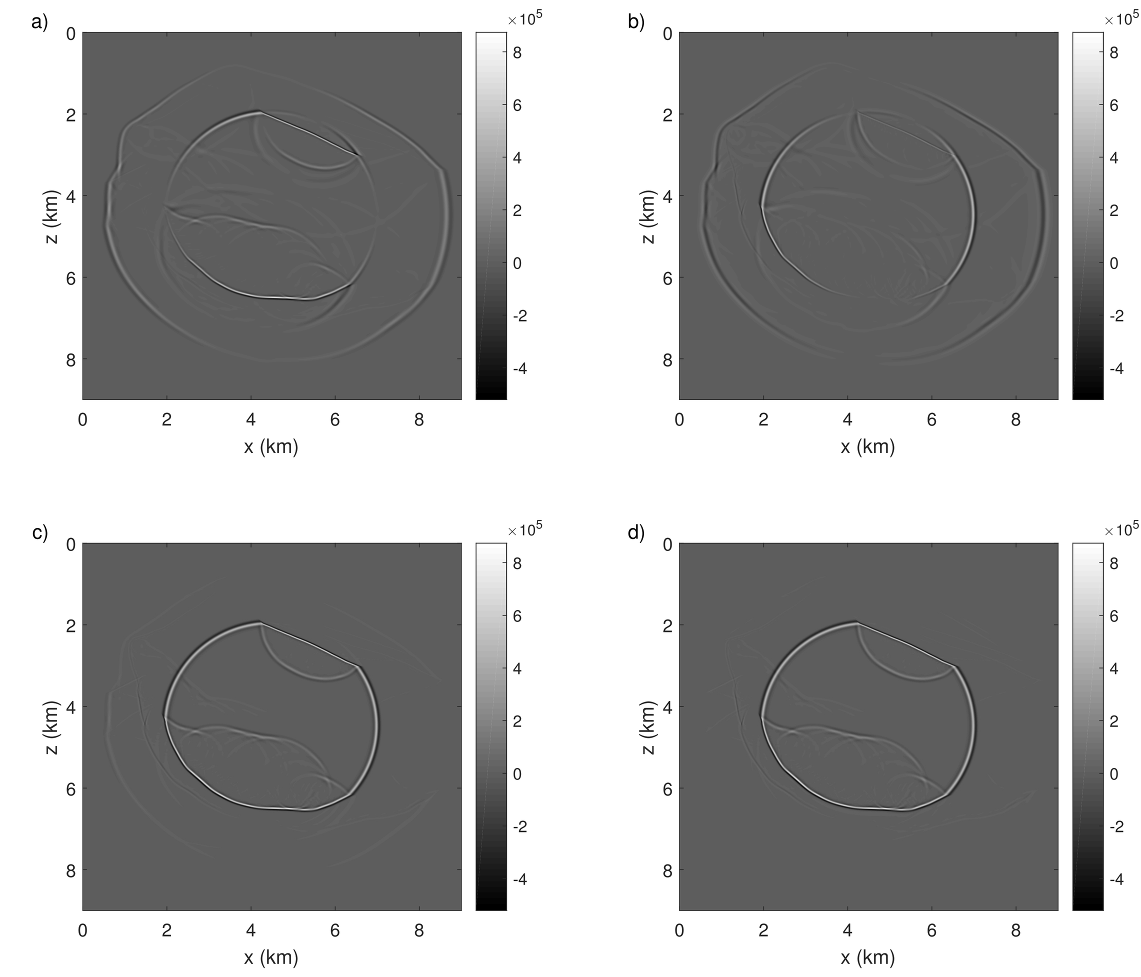

Fig. 5: Synthetic wavefields in SEG/Hess VTI model: a) x- and b) z-component simulated by first-order pseudo-pure-mode qSV-wave equations; c) pseudo-pure-mode scalar qSV-wave field; d)separated scalar qSV-wave field.

Conclusions

- In this study, we have proposed a first-order qSV-wave propagator in general 2D VTI media.
- We have presented synthetic examples of qSV-waves in homogeneous anisotropic VTI medium with weak/strong anisotropy, layered VTI model and part of SEG/Hess VTI model with further projecting the synthetic wavefields onto local anisotropic references to remove residual qP-wave energy.
- The snapshots of x-component at different time demonstrated that Hybrid-PML can be efficiently implemented in this algorithm.

References

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