

# Effective reflection coefficients for curved interfaces in transversely isotropic media

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Plane-wave reflection coefficients (PWRC) are routinely used in amplitude-variation-with-offset (AVO) analysis and for generating boundary data in Kirchhoff modeling. However, the geometrical-seismics approximation based on PWRC becomes inadequate in describing reflected wavefields at near- and post-critical incidence angles. Also, PWRC are derived for plane interfaces and break down in the presence of significant reflector curvature. Here, we discuss so-called effective reflection coefficients  $\chi$  (ERC) designed to overcome the limitations of PWRC for multicomponent data from heterogeneous anisotropic media.

Extending the results obtained by Klem-Musatov et al. (2004) for acoustic models, we show that the reflected wavefield in the immediate vicinity of a curved interface can be represented by a generalized plane-wave decomposition, which includes the local spatial spectrum of the incident wave. Although this decomposition remains accurate near a reflector of arbitrary shape, its computational cost for 3D elastic models is prohibitive. Therefore, we suggest to obtain the reflected wavefield through the ERC defined as the ratio of the displacement of the reflected PP- or PS-wave (projected onto the geometrical polarization direction) and the incident wave. The ERC is approximately computed using the conventional Weyl-type integral for an “apparent” plane reflector, whose distance from the source depends on the incidence angle and the mean reflector curvature.

To incorporate ERC in 3D diffraction modeling, we employ the tip-wave superposition method (TWSM; Ayzenberg et al., 2007) generalized for elastic wave propagation. The superposition of the tip-wave beams corresponding to rhombic surface segments produces correct reflection traveltimes, while the accuracy of amplitudes depends on the validity of the high-frequency approximation used both in TWSM and in the computation of ERC. TWSM is also capable of modeling multipathing and caustics produced by curved segments of the reflector.

We implemented this formalism and studied the properties of ERC for an interface separating isotropic and TI (transversely isotropic) media. The symmetry axis in the reflecting TI halfspace was assumed to be orthogonal to the reflector. For the special case of a plane interface, the ERC gives a close approximation for the exact wavefield (Tsvankin, 2005) governed by the velocity and density contrasts and Thomsen anisotropy parameters. Numerical tests show that the ERC for PP-waves at post-critical incidence angles is particularly sensitive to the parameter  $\epsilon$  responsible for near-horizontal P-wave propagation in the TI medium.

The ERC substantially deviates from the corresponding PWRC (Rüger, 2002) in the post-critical domain, where the displacement field is influenced by the head wave. At low frequencies, however, the difference between the ERC and PWRC may be significant even for sub-critical angles. These results confirm the limitations of the geometrical-seismics approximation, which is based on PWRC, in describing point-source radiation in layered media (Tsvankin, 1995).

The developed methodology can be used to generate accurate boundary data and carry out 3D Kirchhoff-type modeling in anisotropic media. The synthetic example in Figure 1 confirms that ERC eliminate PWRC-related artifacts and produce more accurate amplitudes for large incidence

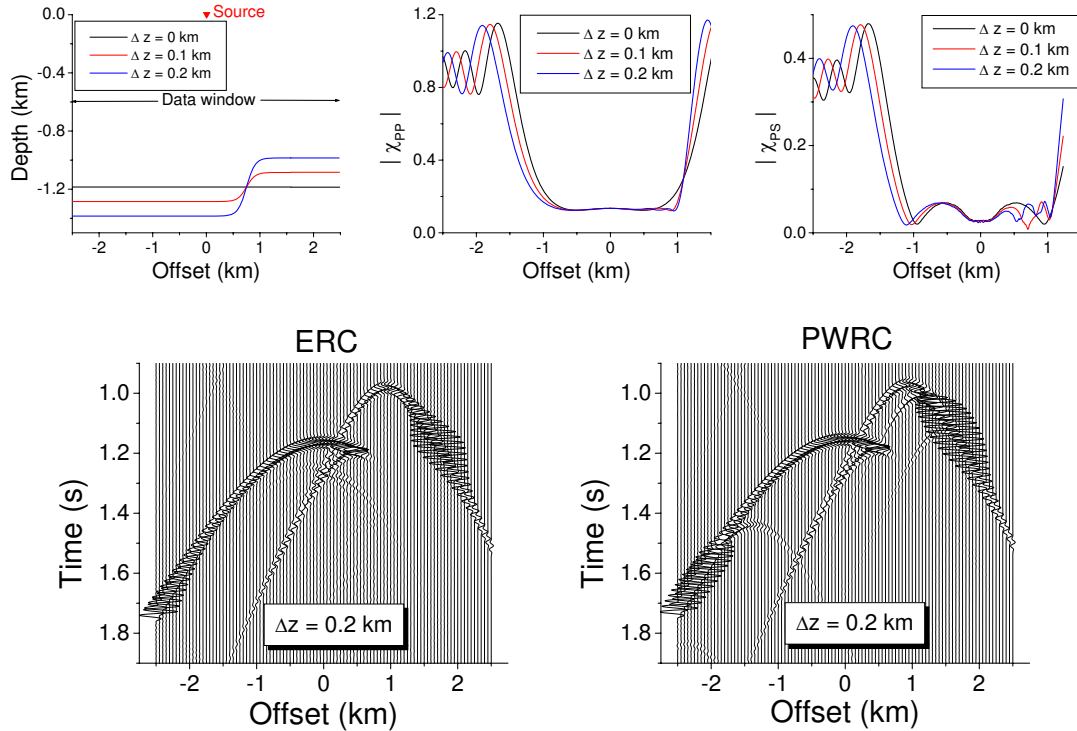


Figure 1: Top row: Model with a curved reflector described by the equation  $x_3 = -1.185 + \Delta z \tanh [2\pi(x_1 - 0.75)]$  (left) and the offset-dependent ERC for PP-waves (center) and PS-waves (right). The P- and S-wave velocity and density of the isotropic incidence medium are  $V_P^{(1)} = 2$  km/s,  $V_S^{(1)} = 1.2$  km/s, and  $\rho^{(1)} = 2.15$  g/cm<sup>3</sup>. For the reflecting TI medium,  $V_{P0}^{(2)} = 2.4$  km/s,  $V_{S0}^{(2)} = 1.4$  km/s,  $\rho^{(2)} = 2.35$  g/cm<sup>3</sup>,  $\epsilon = 0.2$ , and  $\delta = 0.1$ . Bottom row: Vertical PP-wave displacement computed with the ERC (left) and PWRC (right).

angles and in the presence of significant reflector curvature. Note that ERC may change rapidly along a strongly curved interface (Figure 1), which influences the results of synthetic modeling. Our approach can be also applied in anisotropic AVO analysis of long-offset multicomponent reflection data.

## References

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