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Simulation of poro-elastic seismic wave propagation in axis-symmetric open and cased boreholes

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Geophysical constraints with regard to permeability are particularly valuable because they tend to bridge the gap in terms of spatial coverage and resolution that exists for corresponding conventional hydrological techniques, such as laboratory measurements and pumping tests. A prominent geophysical technique for estimating the permeability along boreholes is based on the inversion of Stoneley waves. This technique is by now well established for the hydrocarbon exploration purposes, where the corresponding measurements are carried out in open boreholes and in consolidated sediments. Conversely, the sensitivity and potential of Stoneley-wave-based permeability estimates for shallow hydrological applications is still largely unknown. As opposed to their counterparts in hydrocarbon exploration, shallow boreholes tend to be located in unconsolidated alluvial sediments and hence tend to be cased with perforated or non-perforated plastic tubes. The corresponding effects on Stoneley wave attenuation and its sensitivity to in situ permeability of the formation behind the casing are largely unknown and can only be assessed through realistic modeling. To this end, we present a pseudo-spectral numerical modeling code in cylindrical coordinates that allows for the accurate simulation of complex seismic wave propagation phenomena in realistic surficial borehole environments. We employ Fourier operators along the borehole axis and Chebyshev operators in the radial direction. The Chebyshev operators allows for the use of individual computational sub-domains for the fluid-filled, acoustic borehole, the poro-elastic casing, and the poro-elastic formation surrounding the borehole. These computational sub-domains are connected through a domain decomposition method, which is needed to correctly account for the governing boundary conditions and also allows for substantially enhancing the computational efficiency of our simulations.