Kinematic Forward Modeling of Salt Using the Elastic Dislocation Method with Mapped Geologic Point Attributes and Solution Incrementation

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Abstract

Forward modeling of geologic deformation using the elastic dislocation (ED) method is widely used for fracture prediction, seismic hazard risking, trap analysis, and tectonic reconstruction. The ED approach is based on dislocation of discrete surfaces, such as slip on faults embedded in a uniform linear elastic half space, solved using the boundary element method. This technique retains popularity in reservoir modeling because it is well suited for fast geomechanical analysis of multitudes of faults and horizons with complex morphologies. The ED models are computationally efficient because both dislocations and observation grids exist as surface meshes that can be directly imported from a seismic interpretation or a structural framework model, the nodes do not need to be fully reconciled between intersecting surfaces, and the solutions are linear elastic. This contributes to greatly reduced run times compared to finite element models. In this study, we highlight two key updates to a kinematic forward modeling workflow originally developed to approximate structural deformation related to motion on an underlying, internally deforming salt wall. The first update allows for dislocation vectors to be mapped from an imported point set. This allows for the salt top surface to be assigned a combination of normal and shear vectors as a function of geological position. For example, the crest of the salt wall can be assigned to move upward as a function of depth whereas the flanks of the salt can be assigned reverse or normal shear motion as function of dip. The second update allows for the solution to be broken into time increments, with an option to include geometric nonlinearity. If this option is chosen, the solver will run each increment using the previous increment's deformed geometry as a starting input observation grid, which allows for more realistic progressive deformation. The new features were implemented in a proprietary geomechanics solver and tested on a data set from Salt Valley, Paradox Basin, Utah. Overall, the enhanced workflows provide an efficient kinematic modeling solution that better reflects geologic inputs and allows for more robust calibration to field data. The model is currently being used to predict the evolution of structural deformation and the relationship between ductile salt flow, faulting, and related natural fracture patterns in the adjacent rock mass. The new workflow can also be used for modeling non-uniform fault slip patches and heterogeneous injection and subsidence patterns. The study is applicable to reservoir characterization in salt related structures and analysis of salt cavern integrity in subsurface gas storage.