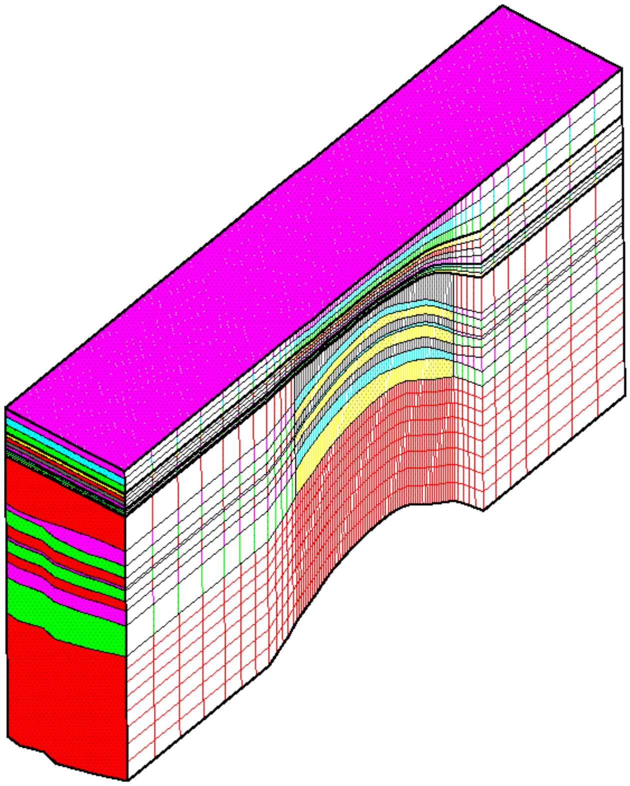
Numerical Simulation of Reservoir Behavior During Primary and Secondary Recovery

Need

Cost-effective improvements in the technology to develop and manage reservoirs in complex environments requires a better understanding of the mechanical and fluid-flow behavior of reservoirs. The relationship between oil or gas production and the mechanical behavior of the reservoir (and / or overburden) can be very complex and difficult to discern directly from field data. Examples of coupled mechanical and fluid-flow phenomena that impact greatly the economics of oil and gas recovery include formation compaction, sand production, and hydraulic fracturing. Numerical simulation can provide critical insight into the behavior of complex geosystems and advance our understanding of the inter-relationship between fluid flow and geomechanical behavior.

Description

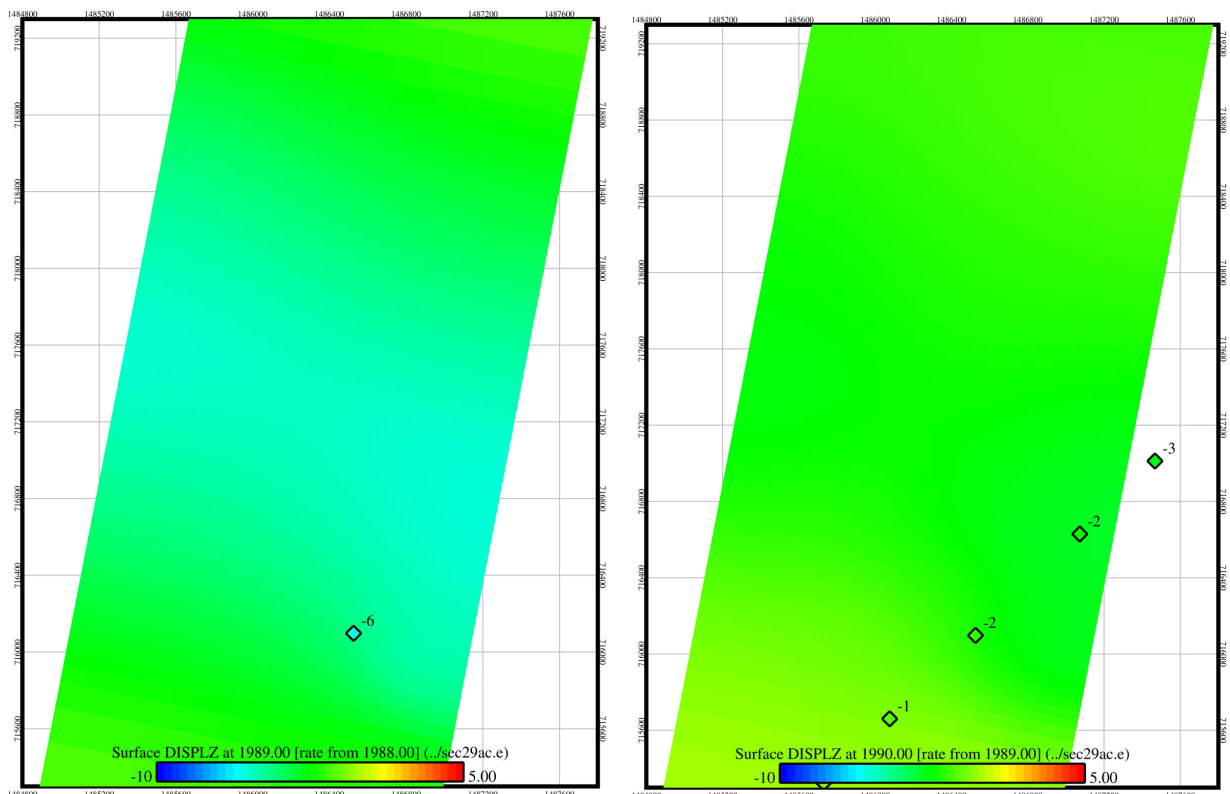
Sandia National Laboratories has developed unique finite element codes that use iterative solution methods that enable the analysis of large-scale, complex geosystems. The codes employ sophisticated material models to properly capture the behavior of non-linear, pressure-sensitive geomaterials. The Geomechanics Laboratory maintains triaxial facilities for testing of core samples for derivation of appropriate material models. JAS3D, a three-dimensional, non-linear, large-deformation finite element code, was applied to improve understanding of the geomechanical processes leading to well casing damage during production from weak, compactable formations. At the Belridge Diatomite Field, located 45 miles west of Bakersfield, California, nearly 1000 wells have experienced severe casing damage during the past 20 years of increased production.



3D finite element mesh used for non-linear geomechanical simulations. The model has >300,000 finite elements and ~ 400,000 nodal points, and contains more than a dozen material layers.

Case Study

A case study of reservoir compaction and well failure at the Belridge Diatomite Field was performed from 1994 to 1998 in close cooperation with an industry partner. The central premise of the numerical simulations was that spatial gradients in pore pressure induced by production and injection in a low permeability reservoir perturb the local stresses and cause subsurface deformation sufficient to result in well failure. Time-dependent reservoir pressure fields that were calculated from three-dimensional finite difference reservoir simulations were input into three-dimensional non-linear finite element geomechanical simulations. The reservoir and geomechanical models covered nearly 20 years of production and injection and were meshed directly from structure maps. The reservoir models contained nearly 100,000 gridblocks (100-200 wells), and the geomechanical models contained more than 300,000 nodal points. Shear strain localization along weak bedding planes that causes casing “dog-legs” in the field was accommodated in the model by contact surfaces. The geomechanical simulations were validated by comparison of the predicted surface subsidence with field measurements, and by comparison of predicted and observed casing damage. Further, simulations performed for two independently developed areas corroborated their different well failure histories. The simulations suggested the three types of casing damage observed. The simulations revealed the evolution of the subsurface stress and displacement fields in the reservoir and overburden, and showed how local production and injection patterns affect their spatial and temporal variation. The simulation approach developed is now being applied by the industry partner as a reservoir management tool to identify optimal operating policies to mitigate casing damage for existing field developments, and to incorporate the effect of well failure potential in economic analyses of alternative infilling plans and operating strategies.



Plan view of numerical predictions of surface subsidence over reservoir area for two successive 1-year increments (in inches, with colorscale ranging from 5 inches of uplift to 10 inches of subsidence). Shown with diamonds is actual subsidence (in inches) measured using field monuments.

References

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