Integrating Multi-Disciplinary Data for Building Fit-For-Purpose 3D Mechanical Earth Model

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SUMMARY

Understanding geomechanics influence early in the field development phase facilitates reservoir management planning. To capture complex geology and associated field development, a 3D Mechanical Earth Model (3D MEM) with Finite Element Method (FEM) approach was selected to analyse the geomechanical related risks associated for two fields in North West Shelf, Australia.

The 3D MEMs were constructed using the geological static models, and seismic derived horizons and faults. The 3D properties were propagated based on core calibrated 1D properties and controlled by stratigraphy, 3D facies and seismic inversion volumes. FEM was used to calculate the equilibrium of stresses and strains within the 3D MEMs. The 3D properties and pre-production stresses were validated in blind test wells prior to forward modelling. The 3D MEMs were linked to the dynamic reservoir models to capture the pressure evolution throughout the field lifecycle.

The results were used to analyse the risks associated with compaction, subsidence, fault instability, completion integrity and drilling stability of infill wells through depleted reservoirs. The results provided insight in managing the risk early in field development stage.

The study's largest challenge was integrating large volume of data to ensure that the structural complexity and rock heterogeneity are captured and consistent with the geological understanding of the field. A multi-disciplinary team of Earth scientists, reservoir, and geomechanics engineers worked together, and the value of data integration, good communication and teamwork were key success factors. Lessons learned and best practices were captured throughout the study and provided valuable feedback for future works.

Key words: Geomechanics, Mechanical Earth Model, Compaction, Subsidence, Wellbore Stability, Fault Stability, Completion Integrity, Well Integrity.

INTRODUCTION

Proper assessments of geomechanical related risks are considered by most operators as a necessary strategic component of exploration and field development activities. Geomechanical studies are important to provide safe drilling parameters not only in exploration wells in virgin areas, but also for development wells and late field life infill wells. Failure to properly manage the risk associated with overpressure and wellbore instability can result in unexpected cost and time overruns.

Reservoir production and injection alter the stress state of the rock and can cause severe field development and production challenges, such as compaction and subsidence, fault reactivation and breaches in caprock integrity. These geomechanical changes can also affect long-term well integrity and cause casing collapse and sanding. Identification of these geomechanical related risks early in the field development planning provides the opportunity to properly manage the risks and minimize their impacts proactively. As examples, well trajectory and completion design can be optimized to minimize the risk of drilling instability and well integrity.

3D Mechanical Earth Models (3D MEMs) enable the capture of all information relating to the stress state, rock mechanical properties and failure mechanism, geological structure and stratigraphy. Finite Element Method (FEM) calculates the stresses and strains for the model to be at equilibrium.

The combination of 3D MEM and FEM approach was selected to analyse the geomechanical related risk associated for two adjacent fields in North West Shelf, Australia. This approach is more advanced compared to the conventional 1D analytical methodologies that, although offer simple and quick solutions, are not suitable for complex geology, rock heterogeneity and inelastic rock behaviour.

DESCRIPTION OF THE 3D MECHANICAL EARTH MODELS WORKFLOW

The 3D MEMs workflow in this study (Figure 1) included (a) data audit and review, (b) construction of 3D geomechanical model, (c) seismic pore pressure prediction for the overburden shales, (d) initialization of pre-production stress state, (e) two-way coupled reservoir geomechanics simulation, (f) wellbore stability analysis and generation of 3D mud weight cubes, and (g) completion integrity.

This workflow integrated a large volume of multi-disciplinary data, such as seismic inversion volumes, seismic horizons and faults in the overburden and reservoir, well log, core data and 1D MEM at the well locations, reservoir static model and reservoir dynamic model. All these data were compiled into a single-platform architecture that allowed easy access and update of the data from the different disciplines within the team. Geophysicist, geologist, petrophysicist, reservoir engineer and drilling engineer were part of the team in addition to the geomechanics engineers.

The construction of the 3D geomechanical model started by taking the reservoir static model and embedding the grid to include overburden, side-burden and under-burden for geomechanical simulation loading purpose. Seismic horizons in the overburden were included as input to the embedment process. Mechanical properties and the constitutive models were populated in the model based on core-calibrated 1D properties. Seismic inversion volumes, 3D reservoir properties and 3D facies were used as secondary inputs to help guide the properties population away from the wells.

Seismic pore pressure analysis was performed to predict the overpressure in the overburden shales. Eaton normal compaction method was used. The Eaton parameters were calibrated and QC'd on the offset wells before being applied to the entire seismic inversion volume. The pore pressure in the reservoir were linked to the dynamic model.

The 3D MEM coupled reservoir geomechanical simulation involves numerical calculation of in-situ stresses and strains throughout the model. The advantage of such a scheme is that a complex stress state can be calculated in a realistic manner by considering the variations in geomechanical property distributions, geological discontinuities as well as the geometry of the reservoir, overburden and ununiform depletion. The pre-production 3-D in-situ stresses in this study were validated to ensure that appropriate boundary conditions were applied to the model. There was less than 3% difference between the stresses from the 3-D model and the 1D models at the location of the offset wells and therefore the 3D model was considered suitable for forward modelling.

For forward modelling, two-way coupled simulation was used. The dynamic reservoir simulator provided pressure to the geomechanical simulator at selected production time-step. The geomechanical simulator calculated the pressure induced stresses and strains for the model to be in equilibrium and the subsequent permeability alteration due to rock compaction. The dynamic reservoir simulator used the permeability alteration as input for the next time-step and the process continued for all the pre-selected time steps.

The results from the two-way coupled simulation were used as input for the subsequent 3D wellbore stability analysis and completion integrity analysis.

ASSESSMENT OF GEOMECHANICAL RELATED RISKS

Over twenty years of production scenario was simulated in this study. The stress state and deformation at any given location within the production lifecycle could now be extracted from the 3D MEMs and used to assess geomechanical related risks within the field (Figure 1).

The magnitude of vertical displacement was extracted to assess the risk of reservoir compaction and seabed subsidence. The predicted compaction and subsidence in this study was small, largely because the rocks were reasonably stiff and strong. There was minimum alteration to the permeability due to the small accumulated volumetric strains and there was no visible impact to the field deliverability. The fault stability risk was assessed based on the accumulated plastic shear strains on the fault elements as well as by way of Coulomb failure criteria using the 3D stresses projected onto the fault planes. Both methods indicated low risk of fault instability in this study throughout the life of the field.

Infill wells are planned at later stage of the field. The two-way coupled simulation results were extracted at the time-step relevant to the timing of the drilling campaign and used to generate 3D mud weight window. The impact of different level of reservoir depletion and how it may affect the stable mud weight window can be easily viewed in the 3D space and the well design can be optimized accordingly. The process could quickly adapt to changes in the well trajectory and timing of the drilling campaign when required.

To assess the risk of the long term well and completion integrity, wellbore centric model was created based on the full field two-way coupled simulation extracted at the planned well location. The wellbore model was refined in the axial and radial directions to incorporate the casings, cements, sand screens and gravel packs. The plastic yield and deformations in the completion elements in this study were small and therefore there was low completion integrity risk throughout the life of the well.

CONCLUSIONS

This case study has showcased the utilization of the latest workflow in advanced 3D coupled reservoir geomechanical modelling to assess geomechanical related risks and to provide technically sound and meaningful results to aid field development planning. Large volume of multi-disciplinary data has been integrated into the 3D MEM on a single platform which can be shared and updated as necessary throughout the lifecycle of the field. The collaboration of the multi-disciplinary team, consisting of geophysicist, geologist, petrophysicist, reservoir engineer, drilling engineer and geomechanics engineer was identified as a key factor to the success of this study.

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