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Understanding the Causation of Shear Induced Casing Failure: Potential Application to Induced Seismicity

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Summary

Induced seismicity is a threat to the petroleum industries social license to operate. Induced seismicity is the result of shear failure on existing fault and fracture planes induced by fluid injection and a change in pore pressure (Raliegh et. al., 1976). An Alberta operator has experienced casing deformation associated with hydraulic fracture stimulation in the Montneny formation. Multi-finger caliper data indicates that the casing is failing in shear with the general orientation of the failure plane being interpretable from the data. This failure occurs in wells proximal to existing fault and fracture networks, but varies in risk between formations. The mechanism is the same as that result in larger scale induced seismicity. Consequently, understanding the casing failure may provide additional understanding of induced seismicity.

A 3D analytical geomechanical model was constructed to understand the variation in casing deformation between formations. The model indicated that the lower zone which is more susceptible to casing deformation is characterised by higher stress anisotropy and greater shear stress resulting in a greater risk of induced shear failure causing casing deformation.

Introduction

Slip on pre-existing faults and fractures has impacts on casing integrity, fault seal and induced seismicity. Casing deformation and loss of production can result from shear failure induced casing deformation, while fault reactivation of trap sealing faults can result in hydrocarbon leakage and is a major exploration risk in some areas (Mildren et. al., 2005), both having negative economic impacts. However, induced seismicity risks the loss of social license to operate and can have a far larger impact than the direct cost or loss of production.

The varied occurrence of casing failure with different formations and geographic locations provides an opportunity to better understand and model the risk of shear failure with a well constrained dataset. This understanding can potentially be used to better understand the risk of shear failure resulting in induced seismicity and mitigate the risk during stimulation and injection.

Method

The risk of shear failure is controlled by the *in-situ* stress tensor and failure envelope of the pre-existing faults (Morris et.al., 1996). One dimensional well based geomechanical models can be constructed using the poro-elastic equations (Plum et. al., 2000), based on an elastic property model. These models are calibrated to closure pressures interpreted from mini-fracture tests and observation of wellbore failure from image log and calliper logs.

Seismic inversion can be used away from well control to construct a 3D elastic property model. This 3D property model can be used to create a 3D geomechanical model using the same process and parameters as applied to the well based elastic properties. The 3D geomechanical model is then used to determine the stress anisotropy and maximum shear stress. The maximum shear stress and stress anisotropy can then be used to assess the relative risk for the magnitude of potential shear failure. However, to properly understand the risk, the distribution and orientation of pre-existing faults and fractures must be understood. This can also be achieved using both seismic properties and interpretation.

Examples

An Alberta operator has experienced casing deformation in horizontal wells in the Montney formation after hydraulic fracture stimulation. The occurrence of the casing deformation varies with location and formation and is primarily observed in one zone close to faults. The dataset available for the field is comprehensive with 3D seismic, multi-finger caliper data of the casing deformation, dipole sonic logs, image logs and mini-fracture data, making it an ideal candidate for investigation.

Rock physics modelling and fluid substitution was undertaken on the wells of interest and the conditioned logs used in the construction of 1D geomechanical models. The models were constructed using the poro-elastic equations (Plum et. al., 2000) with the strain parameters calibrated to a mini-fracture closure pressure. The 3D seismic was inverted for Young’s Modulus and Poisson’s Ratio, creating a 3D property volume, which was then used to create a 3D analytical geomechanical model.

A 1D geomechanical model was constructed for a vertical pilot on a pad with two laterals, one in the upper formation and one in the lower formation. The laterals are drilled in opposite directions, sub-parallel to a large fault. Both laterals have been hydraulically stimulated, but only the lateral in the lower zone has suffered casing deformation issues.

Approximate slippage planes were interpreted from the multi-finger caliper data giving both the orientation and slip-sense of the shear failure leading to casing deformation. The orientations were consistent with local faulting and geological structure. The risk of reactivation was calculated using the 1D geomechanical model from the pilot well and compared to the injection pressures during stimulation. A good match was observed between the failure orientations, and predicted and observed slip sense, suggesting that shear failure of the pre-existing faults is the likely cause of the casing deformation. However, shear failure is also predicted in the lateral drilled in the upper zone in which no casing deformation was observed.

The geomechanical model in the pilot well shows lower stress anisotropy in the upper zone than the lower zone. The magnitude of the shear stress on planes of the same orientation is dependent on the stress anisotropy. Consequently, the magnitude of the shear stress is higher in the lower zone, increasing the risk of any shear failure resulting in casing deformation. However, the vertical location of the laterals varies along their length as do the elastic properties and stress.

The stress anisotropy along the laterals was compared using the stress anisotropy and maximum shear stress estimated from the 3D geomechanical model. The upper lateral was found to be consistently drilled in a zone with a lower maximum shears stress than the lateral drilled in the lower zone. This may explain why casing deformation isn't observed in the upper lateral, but is in the lower lateral.

Conclusions

Variation in casing deformation can be explained by understanding the risk of reactivation, maximum shear stress and stress anisotropy, as it is the shear stress available that directly correlates with the magnitude of the failure event and the energy released. The greater the magnitude, the greater the risk of casing deformation. This is analogous to the risk of induced seismicity, where is it not just the occurrence, but the magnitude of the failure that is important. By building 3D geomechanical models and understanding the variation in both risk of reactivation and maximum shear stress it may be possible to mitigate induced seismicity, analogous to drilling laterals in the upper zone to reduce the risk of casing deformation casing deformation.

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