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Uncertainty evaluation of wellbore stability model predictions☆

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ABSTRACT

There is an increasing concern in the oil and gas industry regarding wellbore stability problems. The need to improve well operations becomes more imperative as the operators move towards more challenging and harsher environments such as ultra-deep waters and high-pressure and high-temperature (HPHT) fields.

Different inconsistencies affect many previous wellbore stability analyses, resulting in incorrect results, or results that cannot be extended to other well configurations by well planners. Typical wellbore fracture and collapse models provide single point estimates of the geopressures. The model input data may be uncertain. Failure to capture these uncertainties has led to poor predictions.

The purpose of this work is to investigate typical fracture and collapse models with respect to in accuracies in the input data with a stochastic method. Uncertainties in the input data, which include in-situ stresses, rock strength data, and pore pressure will be evaluated, to show how these contribute to the cumulative uncertainties in the model predictions.

In this approach, the input parameters are assigned appropriate probability distributions. The distributions are then applied in the wellbore stability models. By means of Monte Carlo simulations, the uncertainties are propagated and the histograms of the outputs are generated. Two types of distributions – triangular and uniform – are applied, to see how the types of input-parameter distributions that are assumed influence the model predictions.

Sensitivity analysis is also conducted. This is to ascertain the most significant input factors, which are largely responsible for the cumulative uncertainties or variabilities in the critical fracturing and collapse pressures.

The proposed methodology can help in reducing many drilling problems such as circulation loss, stuck pipe, and well collapse. As a result, the industry may save much non-productive time. In addition, well planners will have improved information to make critical decisions.

1. Introduction

Wellbore stability analysis is necessary for a safe drilling operation, especially now the oil and gas operators move into more challenging environments and drill highly inclined and extended reach wells. Borehole instabilities are also expected when drilling through shales and unconsolidated sand bodies, fractured carbonates and HPHT formations with narrow safety margins like the Norwegian Central Graben deep Jurassic (Baller, 1991).

According to Mostafavi et al. (2011), one of the main purposes of this pre-drill analysis is to define upper and lower pressure limits for downhole pressure. Many parameters are required, some of which are subject to uncertainties due to measurement errors. Error can also be introduced in data through methods of interpretation used, resulting in poor data quality (Aadnøy, 1988). Another source of input uncertainties is the systemic error due to human imperfect knowledge of subsurface strata. Analytical models used for wellbore stability analysis are associated with uncertainties. Mathematical modeling algorithms only try to approximate physical processes, and they are not true representatives of the problems under study. The modelers should be aware of imprecision and limitations of these physical models. Thus, output uncertainty stems from the variations in input data and

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Nomenclature

P_{wf}	fracture pressure gradient
P_{wc}	collapse pressure gradient
P_o	pore pressure
σ	normal stress
σ_h	minimum horizontal stress
σ_H	maximum horizontal stress
σ_v	overburden stress
σ_1	maximum principal stress
σ_2	intermediate principal stress
σ_3	minimum principal stress
σ_r	radial stress
σ_θ	tangential or hoop stress
σ_z	axial stress
τ_o	cohesive rock strength
α	angle of internal rock friction
τ	shear stress
sg	specific gravity

uncertainties resulting from the wellbore stability modeling processes.

Expected values give no information about uncertainty (Bratvold and Begg, 2010). Deterministic estimate of the downhole pressure limits only provides single-point values that lack variability information. Instead, fully probability distributions can be used. With this approach, cumulative uncertainties in the output predictions can be quantified, leading to an improved decision.

Morita (1995) contributed to uncertainty-based borehole stability assessment, by use of statistical error analysis method. Rock strength, shale swelling, in-situ stresses, and pore pressure were identified as key parameters influencing safe mud weight to maintain wellbore stability. In addition, methods on how to improve wellbore model prediction accuracy through uncertainty reduction were suggested.

Ottesen et al. (1999) defined limit for failure and operationally acceptable magnitude of breakouts in borehole that still guaranteed stability, using quantitative risk analysis (QRA). The modeling results showed that the probability of success was dependent on drilling fluid density.

Liang (2002) also applied a comprehensive QRA methodology to predict pore pressure and fracture gradient. Based on that, the risk of taking a kick and the probability of formation fracture were quantitatively determined.

De Fontoura et al. (2002), based on reliability indexes, presented three analytical methods for evaluating the influence of input parameter uncertainties on wellbore failure modes. Their results were compared with that of Monte Carlo method, and they showed quite good agreement.

Sheng et al. (2006) proposed a numerical geomechanical modeling of wellbore failures, in which a statistical method was incorporated. Mud pressure was singled out as the most influential input variable affecting wellbore deformation. Using Fast Lagrangian Analysis of Continua simulator, and Latin Hyperbole Sampling technique, a range of safe mud weights that guaranteed stable wellbore were predicted.

Aadnøy (2011) offered a new dimension to wellbore stability analyses by showing how the cumulative wellbore model predictive errors, resulting from the input parameter uncertainties, can be quantified. To reduce the model output prediction uncertainties, the paper suggested the need for model calibration against measured or laboratory data.

In addition, Mostafavi et al. (2011) presented a model-based approach to uncertainty wellbore stability assessment with analytical models. The total uncertainties in the fracture and collapse gradient predictions were modeled as the sum of variations embedded in the individual model input parameters. The work also discussed how bottomhole pressure estimation was affected by variations in borehole diameter and fluid density. Quantitative risk analysis was applied to estimate the risk of having wellbore collapse or fracturing.

For uncertainty analysis to be meaningful, it must demonstrate some level of clarity. The approach has to be simple, as to provide transparent information required for subsequent operational decisions. Previous works gave insight into understanding wellbore stability problems. However, some important observations are made.

(1) Some used a derivative-based method in the uncertainty assessment, thereby introducing unwarranted complexity and approximation error in the process.
(2) The wellbore stability simulators used often have limited capacity to handle a wide range of input parameter distributions. Hence, a sensitive sort of analysis, with limited sample space that did not consider good representatives of input data was usually adopted.
(3) In some cases, the constitutive wellbore models were not explicitly shown and discussed.
(4) It has not been clearly shown how the wellbore stability model predictive errors are propagated probabilistically.

In this paper, a fully probabilistic wellbore stability analyses are presented, with pre-exiting deterministic wellbore models as bases. This will also account for the above-mentioned inadequacies of previous uncertainty wellbore stability evaluations. The analyses will be based on Monte Carlos forecast, whereby the model input parameters assume probability distributions. The MATLAB program will be used for the analyses because of its robustness and simplicity. First, a brief theoretical background to this work will be presented.

2. In-situ stress field

In dealing with subsurface structures like a deviated wellbore, three-dimensional stress analysis must be used. Conventionally, a stress state can be specified by six independent components often called stress tensor. The subsurface stresses result mainly from the gravitational loading due to the weight of overburden. Other sources can be attributed to lithospheric plate tectonics, resulting in compressional mountain belts, extensional rifts, subduction and major shear zones (Aadnøy et al., 2009).

The normal stresses are called principal stresses; and they act normal to a plane with no shear stress. The principal stresses are further subdivided into compressive and tensile stresses. In petroleum geomechanics, positive numbers denote compressive stresses. They are described as maximum (σ_1), intermediate (σ_2), and minimum (σ_3) compressive stresses. The tensile stress is assigned negative value by the convention. A stress state is commonly defined by specifying the magnitudes and orientations of these three principal stresses.

Fig. 1 shows different types of stresses acting in rock formations.