Optimisation of borehole trajectory in order to minimize borehole failure

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In the frame of a CTI-project the CHYN and Geo-Energie Suisse AG are developing a workflow and associated software tools that allow a fast decision-making process for selecting an optimal well trajectory while drilling deep inclined wells for EGS-projects. The goal is to minimize borehole instabilities and maximize the intersection with natural fractures. Minimizing borehole instability enhances drilling performance and is required when the open hole is completed with swellable packers. Maximizing the intersection with natural fractures increases overall productivity or injectivity of the well. The specificity of the workflow is that it applies to crystalline rocks and includes an uncertainty and risk assessment framework.

Fundamentally the understanding of borehole failure in deep crystalline well is lacunar because the strength and stress parameters are largely unknown independently. Moreover, there is no agreement on the appropriate failure model required to capture all characteristics of borehole failure. A sensitivity study performed on data from the well BS-1 (DHM project Basel) showed that the most influential parameters on borehole stability are the magnitude of the maximum horizontal stress, the uniaxial compressive strength and the internal borehole pressure.

Three geometry descriptors that are potentially more relevant to packer sealing integrity were investigated: breakout width, breakout depth, borehole cross sectional area and the overall final shape of the borehole. Analytical models assuming an elastic-brittle behavior without stress redistribution were calibrated to these observations using various failure criteria. The commonly used Mohr-Coulomb failure criterion was unable to find calibrated parameters satisfying all failure indicators. Thus, alternative failure criteria were tested eventually showing that a purely cohesive failure criterion with no friction ($\phi = 0°$) allows a more consistent calibration across the failure indicators (Fig.1). This result is consistent with the literature that indicates that breakout formation is a cohesion weakening process (Diederichs, M.S. 2007, Damage and spalling prediction criteria for deep tunnelling). In further analyses, the frictionless failure criterion was used. Another difficulty is that the calibrated models on the vertical borehole section lead to non-unique and inconsistent predictions for deviated wells (Fig.2) because of the very simple model used that cannot entirely capture the failure processes.

Moreover, a pragmatic calibration approach was chosen: firstly, realistic ranges for both SHmax and UCS were computed based on admissible stress limits and secondly, independent data (sonic and density data) were used as a proxy to approximate the strength. Eventually, a complete workflow was developed to provide a systematic approach in selecting the optimum drilling direction. In order to select representative scenarios representing different behaviors substantially affecting the decision, cluster analysis will be performed. In fact, It is a multivariate method which aims to classify the different computed scenarios on the basis of different variables (breakout width, breakout depth, fracture frequency), into a number of different groups such that similar scenarios are placed in the same cluster. These analysis will help to select only distinct scenarios having different behaviors in terms of borehole failure and fracture frequency. These results will form the basis of an integrated workflow optimizing geothermal (EGS) well trajectory.

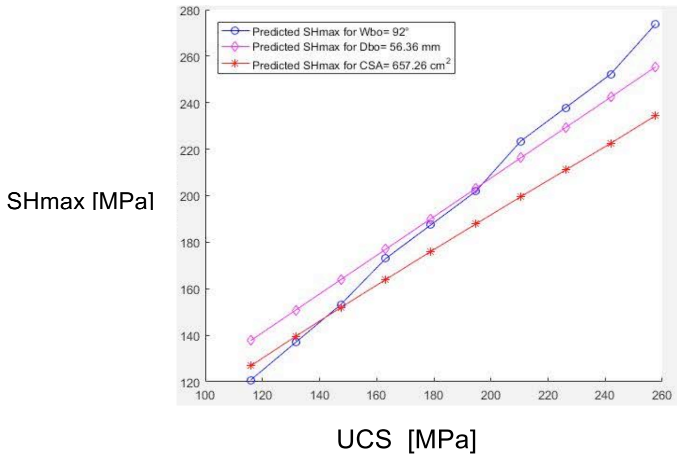

Figure 1. The calibrated couples (SHmax, UCS) for a vertical hole (borehole dip direction = 0°, borehole deviation =0°) for z=3509m with Mohr-Coulomb failure criteria for breakout width calculations and the purely cohesive criteria for both breakout depth and cross sectional area calculations.

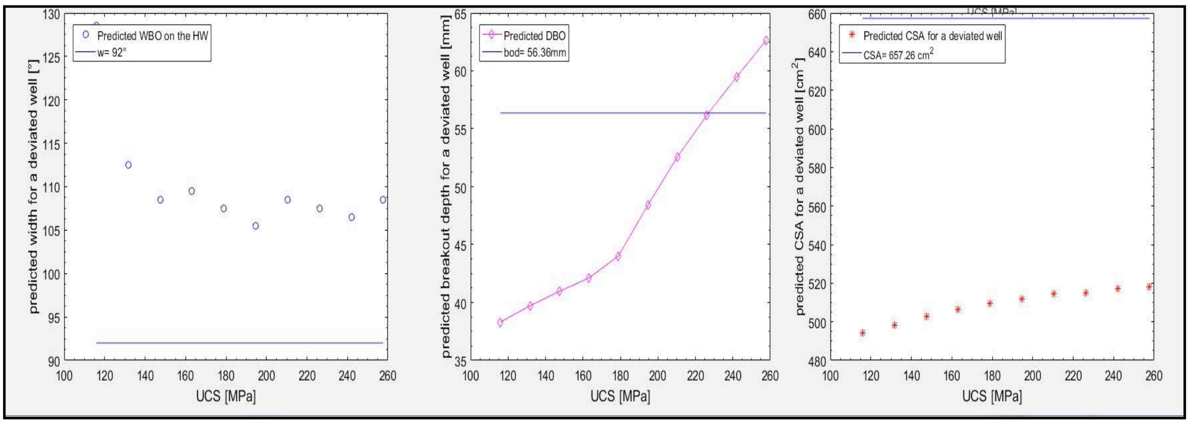

Figure 2. a) The predicted breakout width, b) breakout depth and c) cross sectional area for a horizontal well (deviaton = 90°, dip direction= 0°) using the calibrated couples (SHmax,UCS), obtained in Fig.1. Horizontal lines correspond to the observed values.

REFERENCES

Diederichs, M.S. 2007. The 2003 CGS Geocolloquium Address: Damage and spalling prediction criteria for deep tunnelling. Can. Geotech. J., Vol. 44: 9, pp. 1082-1116(35)