PS An Experimental and Numerical Modelling Study on Stability of Wellbores with Pre-existing Breakouts*

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Abstract

Wellbore instability is a major problem in the oil and gas industry and has been an area of intensive research for a number of decades. Previous research has, however, focused on initial stability for circular wellbores by comparing wellbore stress with formation rock strength, and once the former is greater than the latter, wellbore failure is assumed. There have been very limited studies on stability for wellbores that have already experienced some forms of rock failure on the wellbore wall such as breakouts. Since it is inevitable that wellbore and/or reservoir conditions will change during drilling and production, it is important to understand how wellbores with existing breakouts would response to the changed wellbore and reservoir conditions, and whether the breakouts would remain stable or enlarged further resulting in wellbore collapse. This paper presents a preliminary experimental and numerical study on stability of boreholes with pre-existing breakouts. A series of borehole stability experiments were carried out using a polyaxial cell on weak sandstone samples with a pre-drilled central borehole. The test samples with a dimension of 85mm by 85mm by 100 mm were subjected to 3 independent stresses. The tests were performed by increasing the outer boundary stresses at a given stress ratio until sufficient breakouts were produced. The test samples were then unloaded and the failed materials within the breakout removed manually. The samples with the new borehole geometry were then re-tested with further failure monitored with a borehole camera. It was observed that the failure started from the breakout tip at about 50% of the previously applied maximum stress, but the breakout did not widen until the external load was equal to or greater than the previously applied maximum stress. The borehole stability tests were simulated numerically using FEM and a constitutive model that takes into account strain softening, large deformation and strain. The numerical modelling was conducted to follow the entire experimental process with breakouts formed by removing elements within which the effective plastic strain had reached a critical value. It has been observed that the numerical simulation was able to qualitatively re-produce the experimental observations. The experimental and numerical modelling study revealed new insights on effects of constitutive behaviour and loading history and path on the evolution of stability of wellbores with pre-existing breakouts.

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Introduction

Wellbore instability is a major problem in the oil and gas industry with a widely quoted cost estimate of 2 to 5 billions of dollars per year. It has been an area of research for many years. Previous research has, however, focused on initial instability of a circular wellbore by comparing wellbore stress with formation rock strength, and once the former is greater than the latter, wellbore instability is assumed.

Since borehole breakout is inevitable in some circumstances and that wellbore and/or reservoir conditions will change during drilling and production, it is important to understand how wellbores with pre-existing breakouts would response to the changed wellbore and reservoir conditions, and whether the pre-existing breakouts would remain stable or enlarged further leading to wellbore collapse.

Field Observation and Motivation

Located in shallow water of Bohai Bay, China, Field A was developed with high angle and horizontal wells from an artificial island. The development drilling experienced severe stuck-pipe problems in several high angle and horizontal wells in a short period of several months, resulting in hole collapse, expensive LWD/MWD tools left in the hole and sidetracking. Drilling experience showed that the borehole could be drilled essentially trouble free, however, major problems were encountered while tripping out of the hole. Majority of the problems occurred in the shale formation directly overlying the reservoirs. Postmortem analyses showed that the borehole had already suffered mechanical failure during the drilling stage. However, this did not cause drilling problems because ECD mud weight kept the failed rock on the borehole wall. Several operations during tripping out, such as frequent stop pumping, back-reaming and drill string vibration, might have disturbed the failed rock and caused its detachment from the borehole wall. Fig. 1 shows shale cavings returned during the fishing operation. This and other similar field observations have motivated this study.

Figure 1: Typical recovered shale cavings from Field A in Bohai Bay, China (from Wu and Tan 2010)

Experimental Studies

A series of true triaxial tests was conducted on sandstone block samples that had a dimension of 85 x 85 x 100 mm and a central borehole with a diameter of 17 mm. Fig. 2 shows a photo of the polyaxial cell used for the true triaxial tests. Three independent stresses were applied to the test samples with the maximum and minimum stresses applied horizontally. The vertical stress was equal to the average of the two horizontal stresses. A total of 16 tests were carried out on two sandstones with the horizontal stress ratio ranged from 1.5 to 4. The main objective of the tests was to evaluate the effect of horizontal stress anisotropy on wellbore stability. Some of the results were reported in Wu et al. (2005).

To investigate the effect of pre-existing wellbore breakout on wellbore stability, a sub-set of the tested samples were CT-scanned to determine the failure (or breakout) extent around the borehole. The failed rock material was then physically removed. The samples with a pre-existing breakout were then re-tested following exactly the same loading stress path as applied in the prior test. Deformation and failure of the borehole was monitored with a borescope. Upon completion of the test, the re-tested samples were CT scanned to determine the failure extent. The effect of pre-existing wellbore breakout on wellbore stability is assessed based on failure initiation stress condition and the final failure extent.

Figure 2: Photo of the polyaxial cell

Figs3 and 4 show borehole images taken at failure initiation and end of the tests, and CT scan images at end of the tests.

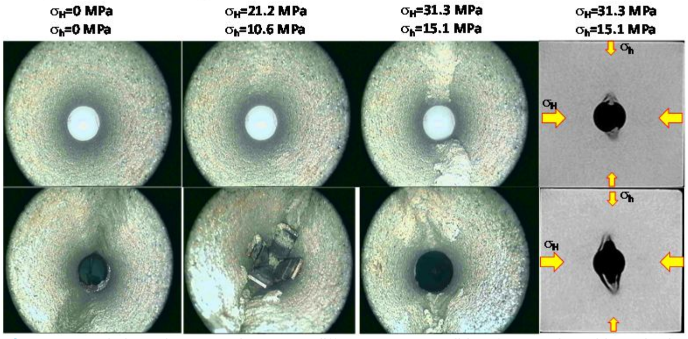

Figure 3: Borehole and CT scan images at different stress condition for samples with a circular borehole and breakout borehole. Horizontal stress ratio is 2.08.

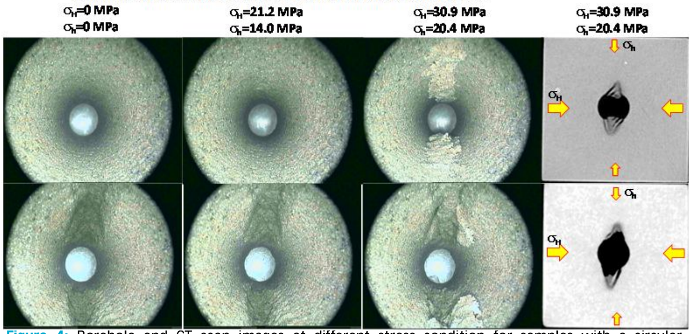

Figure 4: Borehole and CT scan images at different stress condition for samples with a circular borehole and breakout borehole. Horizontal stress ratio is 1.5.

Preliminary Numerical Modelling

A preliminary numerical modelling study was conducted using a 3D finite element model (ABAQUS). The stresses applied at the outer boundaries were increased proportionally in increments with the maximum horizontal stress increased from 0 to 30 MPa. The ratio of the maximum to minimum horizontal stress was 1.5 and the vertical stress was equal to the average of the two horizontal stresses.

The test sandstone was modelled as an elasto-plastic material with strain hardening and softening prior to and post peak strength respectively. Prior to yielding, the material was assumed to be linear elastic. The Mohr-Coulomb criterion was used as yield function with cohesion as a linear function of equivalent plastic strain. The model parameters are summarised in Table 1 based on a set of triaxial tests on the sandstone. Fig. 5 shows some numerical modelling results.

Table 1: M-C Parameters

Parameter	Yield	Peak	Residual
C (MPa)	1.68	3.37	0.02
ϕ (deg)	32.5	32.5	32.5
$\bar{\varepsilon}_{pl}$ (mstr)	0	1.4	9.1

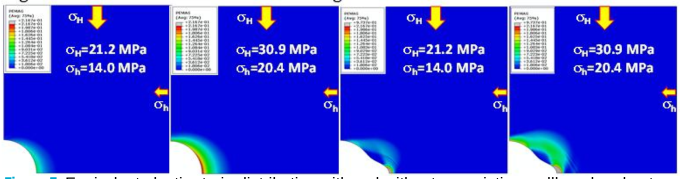

Figure 5: Equivalent plastic strain distribution with and without pre-existing wellbore breakouts

Summary

Experimental results demonstrated that the failure started from the tip of breakout at an external stress that was slightly lower than for a circular borehole at failure initiation. The breakout did not widen until the external stress was equal to or greater than the previously applied maximum stress. The numerical modelling results are qualitatively consistent to a certain degree with experimental observations and further refinement work is ongoing.

FOR FURTHER INFORMATION

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