Drilling and maintaining stable unsupported boreholes in poorly cemented sandy formations

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ABSTRACT

This thesis presents a series of journal and conference articles in which the failure behaviour of an unsupported vertical borehole drilled through poorly cemented sands is studied by analytical, numerical and experimental methods. Also, drilling field investigations were carried out to collect real samples. Three different cement contents and two borehole sizes were considered to study the effects of the bonding strength and scale-size on the particle dislocation. This study resulted in a more realistic prediction of the actual behaviour of this formation in the vicinity of a drilled borehole. Having in-depth understanding on the parameters influencing the borehole status is of significant importance in identifying borehole instability problems, designing adequate borehole supports and choosing an efficient drilling method. Due to poor cementation and therefore granular behaviour of this material, the Discrete Element Method (DEM) was identified as a well-suited tool for developing realistic numerical models. To conduct the numerical simulation, a cube of 8 m^3 made up of spherical particles with diameters ranging from 5 mm to 70 mm was modelled and analysed in a three-dimensional Particle Flow Code (*PFC 3D*). The effects of in-situ stresses around the borehole, strength of particle bonding and fluid flow pressure on the stability of the formation around the borehole have been investigated. The studies showed that when there is lack of sufficient bonding between the sand grains, the interaction between them results in their movement towards the borehole opening and thus eventuates the collapse of the borehole wall. Furthermore, the presence of high pressure water flow expedites the process of the borehole collapse.

To study the behaviour of poorly cemented sands thick-walled hollow cylinder (TWHC) and solid cylindrical synthetic specimens were designed and prepared in the laboratory. The effects of different parameters such as stress path, water and cement content, grain size distribution and mixture curing time on the characteristics of the samples were studied to identify the mixture closely resembling the formation at the drilling site. The Hoek cell was modified to allow the real-time visual monitoring of the grain debonding and borehole breakout processes during the laboratory tests. The results showed the significance of real-time visual monitoring in determining and better understanding the onset of the borehole breakout. The study on the size-scale effect revealed that with the increase in the borehole size the ductility of the specimen decreased, however the axial and lateral stiffness of the TWHC specimen remained unchanged. Under different confining pressures the lateral strain at the borehole breakout initiation point was considerably lower in a larger size borehole (20 mm) versus a smaller size one (10 mm).

Three well-known failure criterion domains; the Coulomb, Drucker-Prager and Mogi, were considered versus the laboratory test data from the TWHC tests to evaluate their ability to predict the shear failure of a borehole. The obtained results showed the significance of selecting an appropriate failure domain for predicting the shear failure behaviour of poorly cemented sands near the borehole wall. The results also showed that the Coulomb criterion is not well suited for predicting the borehole failure when there is no pressure acting inside the borehole. A failure envelope based on the Mogi domain was developed which can be used for the case of the far-field stress states. The introduced failure envelope allows predicting the stability of a borehole drilled in poorly cemented sands. The results from the video recording of the tests showed that a narrow localized zone develops in the direction of the horizontal stress, where the stress concentration causes a full breakout in the specimens. In the TWHC specimens the dilation occurred at lower confining pressures and contracting behaviour was observed during the onset of shear bands at higher pressures. Scanning electron microscopy (SEM) studies showed that sand particles stayed intact under the applied stresses and micro- and macrocracks developed along their boundaries. The SEM imaging was used to investigate and characterize pre-existing microcracks on the borehole wall developed due to the specimen preparation. It showed that boring the solid specimen in order to produce a TWHC specimen can generate microcracks on the borehole wall prior to testing which affects the process of borehole failure development during the test. Detecting the bonding breakage point and introducing an appropriate failure criterion plays a key role in the borehole stability analysis. The total potential and dissipative absorbed strain energy per volume of material up to the point of the observed particle debonding was calculated. The results showed that the particle bonding breakage point at the borehole wall was reached both before and after the peak strength of the TWHC specimens depending on the stress path and cement content. Test results showed that the stress path has a significant effect on the onset of the particle bonding breakage. Also, it was shown that for different stress paths there is a near linear relationship between the absorbed energy and the normal effective mean stress.

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LIST OF PUBLICATIONS

Journal Papers

Hashemi S.S., Momeni A., Melkoumian N. (2013) "Investigation of borehole stability in poorly cemented granular formations by discrete element method". Journal of Petroleum Science and Engineering. 113: 23-35.

Hashemi S.S., Taheri A., Melkoumian N. (2014) "Shear failure analysis of a shallow depth unsupported borehole drilled through poorly cemented granular rock" Engineering Geology, 183: 39-52.

Hashemi S.S., Taheri A., Melkoumian N., Jaksa M. (2015) "The failure behaviour of poorly cemented sands at a borehole wall using laboratory tests" International Journal of Rock Mechanics and Mining Sciences. 77 (2015): 348-357.

Hashemi S.S., Melkoumian N., Taheri A. (2014) "Effect of localised zones in borehole failure in poorly cemented sandy formations" Journal of Petroleum Science and Engineering (Under review).

Hashemi S.S. Melkoumian N. (Submitted 2015) "A new sand dislocation criterion at boreholes drilled through poorly cemented sandy formations" Engineering Geology (Under Review).

Hashemi S.S., Melkoumian N. (Submitted 2015) "Effect of different stress paths on the behaviour of weakly cemented sands adjacent to a drilled borehole" Journal of Petroleum Science and Engineering (Under Review).

Conference Paper

Hashemi S.S., Momeni A., Melkoumian N. "Numerical simulation of borehole breakout in poorly cemented granular sands" The 47th U.S. Rock Mechanics/Geomechanics Symposium, 23-26 June 2013, San Francisco, California, USA.

Hashemi S.S., Melkoumian N., Xu C. "Effect of grain bonding on the stability of a borehole drilled through unconsolidated formations", The 7th Australasian Congress on Applied Mechanics, 9 - 12 December 2012, Adelaide, Australia.

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