Specialist HPD Testing in competent rock to determine the insitu stress

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Assumptions

Firstly to outline the assumptions here:

- The testing is conducted in a competent rock that does not fail in shear at the pressures that can be applied by a HPD test (20MPa). If the material does fail in shear during the test there are alternative analytical techniques that can be applied.
- The entire test is an elastic process, but the expansion is influenced by tensile failure and fracture development.
- Within this document 'Creep' is used in a highly specialised sense and is more akin to instantaneous creep preceding the primary creep behaviour that is a characteristic of all rock under load. Because the observation period is short and identical, it is a near instantaneous stress related elastic creep movement that is entirely recoverable.
- The focus of the HPD testing will be the determination of the stiffness and insitu stress regime. The determination of stiffness is simple and as per a standard HPD rock test, further information is available upon request if required. This document focuses on the specialist HPD testing for the determination of insitu stress, specifically the horizontal stress.

Analytical Techniques

There are currently five different analytical techniques that Cambridge Insitu can apply to look at insitu stress in a competent rock test, including the compass method mentioned. All testing will be undertaken in such a way to allow for the consideration of these techniques, however the rock response may mean certain techniques are deemed inappropriate at the analysis stage. By having several techniques available, there is data redundancy available for validation and optimisation of results.

The simplest procedure is observational and considers the shape of the unload/reload cycles. One of the requirements for a successful unload/reload cycle is that it should be conducted above the insitu stress. Deviation towards asymmetry can indicate that this condition has been violated and the pressure applied has fallen below the insitu stress. If this is the case, an unload/reload cycle will display a dog-leg form or 'banana' shape. If all unload reload cycles are regular then the base of the lowest pressure cycle can be used to set an upper limit for the insitu stress.

Pressure holds (analogous with creep holds) are taken during cavity expansion. These pressure holds are taken at regular intervals for a set period of time (typically 60 seconds). These pressure holds serve two purposes, they allow the rapid removal of any damage that occurred during pocket formation and to identify the first fracture. The first fracture will occur at the tensile stress limit and can be used to approximate the upper limit of the insitu stress. If the tensile strength is known then estimates of the principle stress, normal to fracture orientation can be possible. This technique relies on the assumption that the first fracture is not simply an existing fracture reopening. Results for this technique can be distorted by drilling disturbance and relaxation.

It is advantageous to use cavity contraction data to determine the insitu lateral stress, as there is not typically the influence of disturbance and fracture growth. Like the expansion, a number of pressure holds of a fixed duration are undertaken at regular pressure increments to obtain creep information. These holds are conducted in a targeted zone of the contraction, following crack closure and within the plausible range of the insitu stress. For example, a range of $2\sigma_v$ to $0.5\sigma_v$. A minimum of 10 fixed pressure increments are recommended to provide adequate detail. The magnitude, rate and direction of creep movement can then be assessed. Points of inflection and deviation from the general creep trend are significant indicators of a principle stress boundary being crossed. From this technique the magnitude and ratio of the insitu stress can be derived (but not the orientation). If cavity contraction data is lost- for example if a membrane rupture occurs, then this technique cannot be applied.

For a vertical test a compass can be installed to the HPD and the orientation and the ratio (but not the individual magnitudes) of the insitu horizontal stress can be inferred from the ratio derived from anisotropic stiffness. This concept was first developed by Dalton & Hawkins [1982] and there has been recent experimental work (for example Liu et al [2021]). The technique relies on applying a Mohr's circle calculation to three equally spaced stress vectors in the same plane. This information can be obtained from HPD considering the three planes of symmetry. Unload/reload cycles should be used as the data source to ensure minimal influence of probe movement and disturbance. This technique is particularly powerful in environments where there is significant horizontal anisotropy. It can challenging to apply if the ratio of major to minor horizontal stress (σ_H/σ_h) is less than 1.2.

If four or more successful unload/reload cycles are undertaken, the stress dependency exponent can be considered. The development of shear modulus with stress can be used to predict the *minimum* modulus that applies at the initial stress state. The best estimate of initial stress can therefore be inserted into these power curve relationships as a rough check on the plausibility of the derived values. If fracture development occurs during the expansion and the unload reload cycles are influenced by fracture growth, the regression is typically poor and this technique cannot be used with confidence.

The paper attached discusses four of these techniques, with a focus on using the cavity contraction data (please note this is not yet published but has been accepted to the IRSM Eurock conference later this year).

Calibration of the HPD

Calibration of the HPD is vitally important for high pressure rock testing. In addition to the standard membrane and system stiffness calibrations, Cambridge Insitu conduct a spring specific check. This to ensure that any anisotropic response of the instrument is calibrated out and does not influence the results. This calibration is key if part of the project goals are to understand whether anisotropic horizontal stress regime exists, especially if anisotropic stiffness is being considered.