SENSITIVITY OF TOTAL STRESS TO CHANGES IN EXTERNALLY APPLIED WATER PRESSURE IN KBS-3 BUFFER BENTONITE

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INTRODUCTION
In the KBS-3 concept, composite copper and steel canisters containing spent nuclear fuel will be placed in large diameter disposal boreholes drilled into the floor of the repository tunnels. The space around each canister will be filled with pre-compacted bentonite blocks. Over time, the bentonite blocks will draw in the surrounding groundwater and swell, closing any construction gaps to encapsulate the waste in a low permeability barrier.

From a performance assessment perspective, the effect of glacial loading of a future repository and the resulting change in local porewater pressure is an issue that must be addressed. For a clay-water system with the porewater in thermodynamic equilibrium with an external reservoir of pure water at pressure, \( p_w \), the total stress acting on the clay, \( \sigma \), can be expressed as

\[
\sigma = \sigma_i + R - A + p_w \tag{1}
\]

where \( \sigma_i \) is the “interparticle stress” and \( R \) and \( A \) are the repulsive and attractive stresses respectively (Lambe, 1960). In conventional soil mechanics theory the effective stress \( \sigma_{\text{eff}} \) (Terzaghi and Peck 1967) is defined as the difference between the total stress and the measurable pore pressure. Since distilled (pure) water was used in this experiment we can write the relationship:

\[
\sigma_{\text{eff}} = \sigma - p_w = \sigma_i + R - A \tag{2}
\]

For dispersed and highly plastic saturated materials such as bentonite which exhibit no mineral to mineral contact the interparticle term \( \sigma_i \) reduces to zero (Lambe and Whitman, 1969), and the effective stress equation simplifies to:

\[
\sigma_{\text{eff}} = R - A \tag{3}
\]

where \( R-A \) is equivalent to the swelling pressure, \( \Pi \), of the clay. Recent work by Harrington and Horseman (2003) examining the sensitivity of total stress to changes in the externally applied water pressure demonstrated the general validity of the effective stress law. However, to account for minor departures in ideality, Harrington and Horseman introduced a proportionality constant \( \alpha \) (equal to \( \sigma/\Pi \)) leading to:

\[
\sigma = \Pi + \alpha p_w \tag{4}
\]

The observation that \( \alpha \) may not be equal to 1 has led to the suggestion that as the externally applied porewater pressure increases, swelling pressure (in this case equivalent to the effective stress) may actually decline to the point where liquefaction of the bentonite occurs. This paper presents the original results from Harrington and Horseman (2003), outlines some of the uncertainties associated with extrapolation of such data and discusses in detail a new test history performed at elevated porewater pressures up to 46 MPa.

RESULTS
Two experimental histories (designated Mx80-10 and Mx80-11) have been undertaken using a custom-designed constant volume and radial flow (CVRF) apparatus (Horseman et al., 2004). In both tests
backpressure was varied in a number of incremental and decremental cycles while total stress, porewater pressure and volumetric flow rate were continuously monitored.

The swelling pressure of the buffer clay at dry densities of 1.58 Mg.m\(^{-3}\) and 1.61 Mg.m\(^{-3}\) was determined to be around 5.5 MPa and 7.2 MPa respectively. Initial histories of ascending porewater pressure yield \(\alpha\) values of 0.86 and 0.92 for tests Mx80-10 and Mx80-11 respectively.

During the initial ascending porewater pressure history both tests exhibit a general trend of increasing \(\alpha\) with increasing backpressure. Analysis of the water inflow data for Mx80-11 indicates a similar trend, symptomatic of a reduction in system compressibility. The initial non-ideality of \(\alpha\) can be explained by a number of factors such as interplatelet friction, compression of residual gas, the movement of gas into solution, sidewall friction and apparatus compliance. However, net inflow data indicates the specimen is fully saturated early in the test history, suggesting an alternative mechanism may exert a dominant role on the mechanical behaviour of the system.

Asymptotic values of porewater pressure measured on the surface of the specimen are in good agreement with the externally applied backpressure values. Changes in applied porewater pressure are generally mirrored within the specimen within around 2 to 10 days of the change in boundary condition. Inspection of data provides no evidence for the development of hydraulic thresholds within KBS-3 bentonite subject to these test conditions.

Analysis of the stress data clearly demonstrates significant hysteresis exists when externally applied backpressure is reduced. Comparison of effective stress data (i.e. swelling pressure) for both test histories indicates a clear trend between the amount of hysteresis observed and the absolute magnitude of the backpressure applied to specimen. This suggests that the observed hysteresis results from some form of “stress memory” and not experimental compliance. The strength of this phenomena appears to be dependent on the magnitude of the backpressure applied to the specimen.

At porewater pressures of 46 MPa the bentonite still retains a significant proportion of its original swelling ranging between 48 and 67% depending on the test cycle. The data also indicates a reduction in the rate of decline in swelling pressure as backpressure increases, indicative of a rise in \(\alpha\) values at high water pressures. Linear regression suggests \(\alpha = 1\) at a porewater pressure of around 64 MPa.

At the end of test Mx80-11 the average effective stress was 14.4 MPa, represents an increase in the total stress of 100% and is an obvious artefact of the apparent stress memory mentioned above. If correct, this has important implications for repository performance assessment.

No evidence of classic liquefaction was found in this experimental study.

References


