Lab experiments for the mechanical behavior of different shales and claystones

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Determining the mechanical behaviour of shales and claystones is still challenging for practitioners who have to deal with engineered rock structures. This is particularly true for underground structures designed for deep geological disposal of high-level radioactive waste since delayed deformations and time-dependent damage to the rock mass have to be predicted over long periods of time in order to ensure human and environmental safety.

In this context, any numerical simulations require appropriate constitutive models that can account for the more relevant phenomena (e.g. Chemo-Hydro-Thermo constitutive equations) [1], [2], [3]. Most of the time, rate dependent constitutive models belonging to the visco-plasticity family are used [4]. Whatever the chosen constitutive model, it is necessary to properly identify and calibrate the geomaterial parameters. In a first stage, lab tests performed on core specimen are the best option, although later field measurements and back analyses can be used to account for any scale effect.

This presentation summarizes the results of lab tests performed on three rocks characterized by a high clay content [5]. The time-dependent behaviour of these sedimentary rocks was studied under different loading conditions in uniaxial compression. Static or cyclic creep tests and strain rate controlled tests were performed across various orientations of the fabric of the specimens. The tests carried out under a low strain rate showed similarities in the mechanical response for all three argillaceous rocks, with a late phase of dilation and a linear development of volumetric deformation before the onset of unstable crack propagation. The development of secondary and tertiary creep phases during the creep tests highlighted the existence of a stress deviator threshold, below which only primary creep is observed. Long-term creep tests also showed that the volumetric variation is not constant during the development of time-dependent deformations.

In addition, ultrasonic measurements gave valuable information about the development of specimen damage [6]. The longitudinal and transverse wave velocities are clearly related to the physical and mechanical characteristics of the rock. Throughout the experiments, the dilating behaviour of an argillite could be correlated with a decrease of the P-wave velocity. The results show that P-wave velocity measurements during a creep test can distinguish the three different phases of creep. During primary creep the P-wave increases due to pore closure. The secondary creep phase, characterized by a constant strain rate, is identified by a linear decrease of the wave velocity; this trend accelerates during tertiary creep.

The analysis of crack patterns in argillaceous rocks, induced by time-dependent mechanical deformations, was based on observations of thin sections extracted from specimens after testing [7]. The micro-structural observations, made using an Optical Microscope (OM) and a Scanning Electron Microscope (SEM), highlighted the fact that the crack patterns and failure modes of the specimens are dependent on the rate of loading. For slow loading rates, the macroscopic deformations appear to be mainly due the development of a sub-vertical network of persistent macro-cracks in the argillaceous matrix, while for the fast loading tests, a second network of micro-cracks appear, controlled by the rock's structural anisotropy. When the specimens undergo fast loading, the observed failure is more brittle with cataclastic deformation and grain crushing in evidence within the samples. Observations of the crack width and crack orientations clearly show how the crack patterns influence rock properties, such as permeability, which is a key parameter in the Damage Zone that develops around many geo-engineered structures.

The last part of this experimental investigation dealt with the shear strength of rock discontinuities, which strongly depends on the water content especially when the rocks contain clay minerals [8]. To assess the decrease in the mechanical properties of clay-infilled discontinuities due to water saturation, a series of direct shear tests was performed using an advanced shear box that allows the injection of water into the discontinuity. Results show that both the friction coefficient and the cohesion decrease when the discontinuity is saturated. Overall, the shear strength of the discontinuity is considerably reduced, to approximately 50% of its original value. This reduction has to be accounted for when conducting stability analyses of rock slopes, dam foundations or underground openings.

These experimental investigations can be used together to ascertain the mechanical properties of shales and claystones. As mentioned previously, field measurements conducted at a true scale in underground structures, as well as geophysical monitoring, are required to adjust the final mechanical parameters in the numerical simulations.

References

1- F. Pellet, M. Roosefid, F. Deleruyelle, (2009), On the 3D numerical modelling of the time-dependent development of the Damage Zone around underground galleries during and after excavation, Tunnelling and Underground Space Technology, vol 24, 6, pp 665-674.
2- F. L. Pellet (2009), Contact between a tunnel lining and a damage-susceptible viscoplastic medium, Computer Modeling in Engineering and Sciences, Tech Science Press, vol. 52, 3, pp. 279-296.
3- E. Boidy, A. Bouvard, F. Pellet (2002), Back analysis of time-dependent behaviour of a test gallery in claystone, Tunnelling and Underground Space Technology, vol 17, 4, pp 415-424.
4- F. Pellet, A. Hajdu, F. Deleruyelle, F. Besnus (2005), A viscoplastic constitutive model including anisotropic damage for the time dependent mechanical behaviour of rock, International Journal for Numerical and Analytical Methods in Geomechanics, Wiley, vol 29, 9, pp 941-970.
5- G. Fabre, F. Pellet (2006), Creep and time dependent damage in argillaceous rocks, International Journal of Rock Mechanics and Mining Sciences, vol 43, 6, pp 950-960.
6- F. Pellet, G. Fabre (2007), Damage evaluation with P-wave velocity measurements during uniaxial compression tests on argillaceous rocks, International Journal of Geomechanics, American Society of Civil Engineers (ASCE), vol. 7, 6, pp 431-436.
7- F.L. Pellet (2014), Micro-structural analysis of time-dependent cracking in shale, Environmental Geotechnics, accepted for publication.
8- F.L. Pellet, M. Keshavarz, M. Boulon (2013), Influence of humidity conditions on shear strength of clay rock discontinuities, Engineering Geology, vol 157, pp 33-38.