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Experimental Studies of Stress Dependence, Static vs Dynamic Behaviour and Mechanical Anisotropies of Shale

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SUMMARY

Laboratory data from controlled rock mechanical tests with various shales have been used to understand and quantify stress effects on wave velocities of relevance for 4D seismics, and to quantify the difference between static and dynamic mechanical properties and their anisotropies.

Introduction

There is increasing industrial need for characterizing and understanding how shales behave under stress. Time-lapse ("4D") seismic reveals stress changes in the overburden above depleting reservoirs through increased travel times in the overburden (Kenter *et al.*, 2004), which in order to become quantitative requests knowledge of stress dependent seismic velocities under the relevant in situ stress path. Cap rock integrity above producing reservoirs or injection sites for e.g. CO_2 storage needs to be evaluated on the basis of stress changes and mechanical properties of shale. In gas / oil shale reservoirs, design of fracturing operations should be based on knowledge of the stress field and a fundamental understanding of how fractures initiate and grow in heterogeneous low permeability rocks, often in the presence of natural fractures.

Overburden and reservoir shales tend to be very different in composition and have a wide spread in their petrophysical and mechanical properties. In spite of these differences, there are common features: All shales exhibit some level of intrinsic anisotropy associated with their texture. Anisotropy may however also be induced by applied stress, and the interplay of lithology and stress is important to understand.

Experimental studies

Laboratory experiments have been performed with a variety of shale cores, including overburden and outcrop rocks representative of both cap rocks and gas shales. The experiments have focussed on measurements of stress path dependent ultrasonic velocities, to be linked to 4D applications. The static mechanical behaviour has also been measured, so that possibilities for cap rock failure as a result of depletion / inflation can be addressed. The relationship between static and dynamic is addressed in particular, since the difference in many cases is substantial (Holt *et al.*, 2012). In order to point out the role of anisotropy on mechanical behaviour, unconfined and confined strength tests with samples having different orientations with respect to the bedding plane have been performed.

Experimental results

Figure 1 shows an example from a laboratory test, where a specimen of compacted brine-saturated kaolinite has been loaded along different stress paths. The stress dependence is also stress path dependence, a fact which may appear obvious, but often is neglected when applying rock physics to field cases. The constant mean stress path with axial unloading mimics the stress path in the overburden as a result of depletion of an underlying reservoir (Holt and Stenebråten, 2013). Stress path dependence applies not only to velocities, but also to velocity anisotropies.

Dynamically determined elastic moduli normally exceed their static counterparts. This is shown in several experiments with different shales. The difference may be related to strain amplitude effects and to frequency dispersion. In experiments with unconfined loading of differently oriented specimens of Mancos Shale (a gas shale analogue), P-wave velocity anisotropy was measured and converted to anisotropy in dynamic Young's modulus. The observed difference between static and dynamic Young's modulus is discussed further with respect to its possible physical origin, such as dispersion and strain amplitude effects.

Conclusions

Laboratory data from controlled rock mechanical tests with various shales have been used to understand and quantify stress effects on wave velocities of relevance for 4D seismics, and to quantify the difference between static and dynamic mechanical properties and their anisotropies.

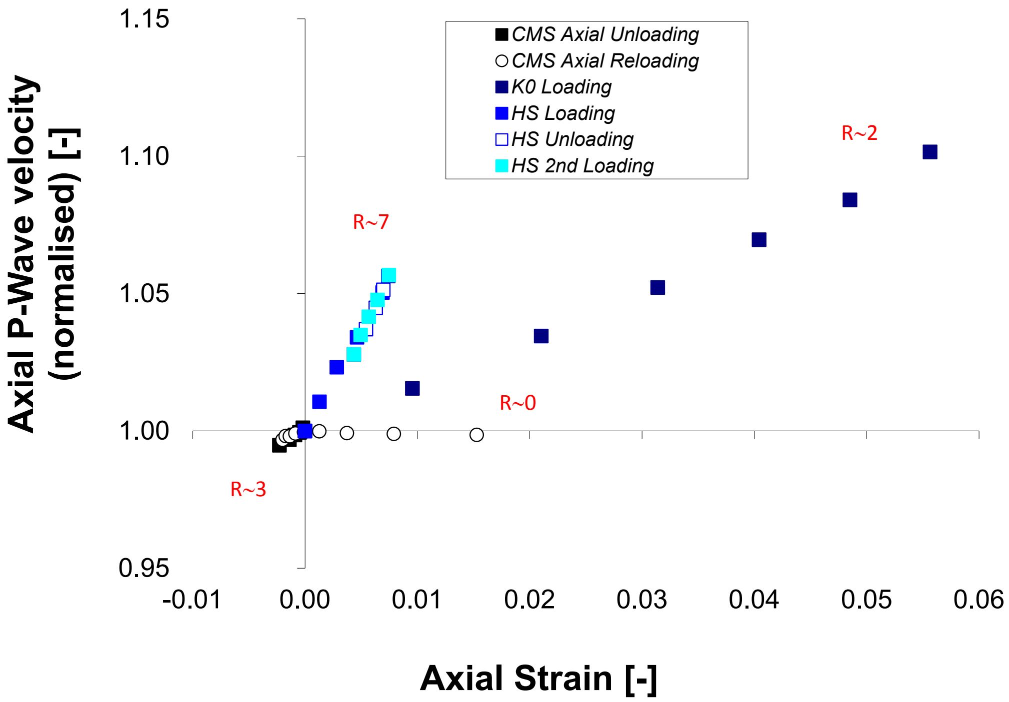

Figure 1: Strain dependence expressed by the dilation parameter $R = \frac{1}{v_{Pz}} \frac{\Delta v_{Pz}}{\Delta \varepsilon_z}$ *for the folowing stress paths: CMS (constant mean stress), including axial unloading and reloading;* K_0 *loading (uniaxial compaction), and HS (hydrostatic) loading, unloading, and reloading. The specimen was pure kaolinite compacted in 3.5 % salinity brine.*

References

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