Do wave velocities really depend on stress?

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Introduction

It is well established that elastic wave velocities depend on stress (Wyllie et al., 1958). At least, it is convenient to assume that they do. However, given the close relationship between stress and strain, it may well be that the velocities actually depend on strain rather than stress, or both. Or something else. In some situations, it may be essential to know these dependencies, in order to interpret observed velocity changes correctly.

Methods

During loading/unloading sequences, there is normally not a one-to-one relationship between stress and strain. This gives an opportunity to distinguish between stress and strain dependency. Also during hold periods, where the stress is kept constant while the rock is deforming in a creep process, it is possible to distinguish one dependency from the other. We shall here discuss some results from such measurements on dry Castlegate sandstone.

Results

Fig. 1 shows the stress and strain dependency of the axial P-wave velocity measured during a loading/unloading sequence under uniaxial strain conditions. The confining stress is in the range 10-12 MPa and the rock is far from failure. Clearly, the velocity shows a nearly one-to-one relationship with stress, but not with strain. Hence, the verdict is in favour of stress dependency in this case.

Fig. 2. shows how the axial P-wave velocity changes with strain in a uniaxial stress test where the rock is creeping through failure under constant stress. The velocity changes with strain in a way that resembles the variations around the peak stress point in an ordinary failure test, however in this case the stress remains constant and can not be the cause for the velocity variations. Thus, the velocity clearly depends on strain, not stress in this case.

Significant increase in axial P-wave velocity was also observed in hold periods following a reduction in axial stress. During these periods, both stress and strain were nearly constant, hence there must be some other cause for the velocity alteration in these cases.
Discussion

It has been argued that opening and closure of cracks depend on normal stress and shear strain, and that these effects have a dominating impact on wave velocities (Fjær, 2006). Thus, one may expect that the velocities depend primarily on stress when the rock is far from failure, whereas strain dependency dominates in the vicinity of shear failure, in agreement with the observations shown in Figs. 1 and 2.

The increase in velocity observed during the hold periods after stress reduction can not be explained exclusively by the same arguments, since neither stress nor strain change significantly during these periods. One possible explanation could be that some of the micro-cracks that opened up due to unloading are gradually saturated with water that has condensated on the grain surfaces.

Conclusions

Wave velocities do indeed depend on stress, however they also depend on strain, particularly in the vicinity of shear failure. Other effects, possibly related to redistribution of small amounts of fluid, may also play a significant role.

Acknowledgements

This work was supported by the SINTEF Petroleum Research project "Shale as a Permanent Barrier after Well Abandonment", sponsored by the Norwegian Research Council, BP, ConocoPhillips, Det norske oljeselskap, Shell, Statoil and Total.

References
