FORMATION AND EXTENSION OF COMPACTION BANDS IN POROUS ROCK

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Thin, approximately planar bands of localized compaction have been observed both in the field and laboratory samples. Because the permeability of these bands is several orders of magnitude less than the adjacent material, understanding their formation and evolution is important to a variety of applications involving subsurface fluid injection or withdrawal, e.g., energy storage and recovery, aquifer management and CO_2 sequestration. A theory that treats the formation of these bands as an alternative solution to uniform compression shows that such localization is possible for inelastic compacting materials and, in agreement with laboratory observations, for stress states on a "cap" yield surface, for which the shear stress needed for further inelastic deformation decreases with increasing compressive hydrostatic stress. Specific calculations for an elliptic cap surface with aspect ratio inferred from laboratory results predict a minimum confining stress at which bands form [1]. Although this prediction is roughly consistent with laboratory observations, quantitative comparison with results for several sandstones is poor.

Extension of the bands to lengths of 10's of meters observed in the field is less well understood. The stress state immediately ahead of the band can be calculated by modeling the band as a narrow elliptical inclusion of stiffer material (because of decreased porosity) subject to an imposed inelastic compressive strain and loaded by stresses in the far field. For aspect ratios and inelastic strain values inferred from field data and plausible values for the stiffness contrast, the calculations show that the bands can reasonably be approximated by an "anticrack" which neglects the stiffness of the inclusion and idealizes the compactive strain as interpenetration of the surfaces of a negligibly thin crack [2]. This result is supported by a calculation of the elastic strain energy released per unit advance of a compaction band in an infinite layer of thickness h [3]. If the elastic moduli of the band and the surrounding host material are similar and the band is much thinner than the layer, the energy released is simply $\sigma_+ \xi h \epsilon^p$ where σ_+ is the compressive stress far ahead of the band edge, ξh is the thickness of the band and ϵ^p is the uniaxial inelastic compactive strain in the band. Using representative values inferred from field data yields an energy release rate of 40 kJ/m^2, which is roughly comparable with compaction energies inferred from axisymmetric compression tests on notched sandstone samples. This suggests that a critical value of the energy release rate may govern propagation, although the particular value is likely to depend on the rock type and details of the compaction process.

References

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