Elastic Constants and Strength of Berea Sandstone

ABSTRACT: The behavior of Berea sandstone was studied for three loading paths: hydrostatic compression, confined compression, and uniaxial strain. Compressional and shear wave velocities were measured simultaneously. Static and dynamic elastic moduli were computed; the dynamic exceeded the static at each stress level. Confined compression to failure experiments were performed at confining pressures of 0, 10, 25, and 40 MPa. The strength and Young's modulus increased with increasing confining pressure.

INTRODUCTION

Variations in the elastic and flow properties depend not only upon the state of stress but also upon the stress path. Studies of reservoir compaction show that the volumetric strain due to reservoir depletion is related to the boundary conditions. In order to characterize the behavior of the reservoir, the rheology and flow must be determined for different stress paths, and fracture criteria must be developed to predict shear failure.

EXPERIMENTAL PROCEDURES

Hydrostatic compression, uniaxial strain, and confined compression measurements were performed on room dry Berea sandstone. Berea is a massive, light tan, medium to fine grained sandstone cemented with silica and clay. Its composition is 75.5% quartz, 16% feldspar, 5% kaolinite, 0.5% carbonate. The dry bulk density is 2.1 g cm^{-3} and the porosity is 17.8%.

The experiments were carried out in a servo-controlled test apparatus. Confining pressure was generated and maintained with an independent servo-hydraulic intensifier.

The specimens were jacketed in 0.13 mm thick copper and mounted between a matched set of velocity transducers. The strains were measured with strain gages (hydrostatic compression and uniaxial strain) and LVDTs mounted on the specimen (confined compression). The tests were conducted in accordance with ASTM recommended procedures.

EXPERIMENTAL RESULTS

Elastic Properties: Mean stress is plotted as a function of volume strain for two leading paths, uniaxial strain and hydrostatic compression. The stress-strain curves are concave upward. The rock exhibits hysteresis during unloading for both stress paths. Volume change per increment in mean stress is less for uniaxial strain than for hydrostatic compression. For example, The volume compaction of the specimen at a mean stress of 75 MPa is nearly 13% less in uniaxial strain cycle than hydrostatic compression.

The velocity data show a small stress dependence in hydrostatic compression. The effect is most pronounced for compressional velocity at mean stresses below 20 MPa.

The dynamic moduli exceed the static at all stress levels. Typically, the ratios of dynamic to static bulk moduli range from 1.06 to 1.13. For example, in uniaxial strain the dynamic and static bulk moduli at a mean stress of 33 MPa are 18.7 and 17.1 respectively.

Confined Compression to Failure: Sixteen specimens were tested at confining pressures (σ_3) of 0, 10, 25, and 40 MPa. The results of a typical experiment at a confining pressure of 10 MPa are presented. The axial strain is not a linear function of stress difference $(\sigma_1) - (\sigma_3)$. At low stresses, the slope is concave upward (suggesting closing of pre-existing cracks and pores), nearly linear between 25 and 75 MPa, and concave downward (due to propagation of cracks) above 75 MPa. The specimen failed with well defined shear fracture at a differential stress of 122 MPa. Young's modulus, E, was 20.8 and Poisson's ratio, ν, was 0.27.

Mean Values for Confined Compression Tests

σ_3	*E*	ν	$\sigma_1 - \sigma_3$
MPa	*GPa*		*MPa*
0	*15.2*	*0.37*	*66.6*
10	*20.9*	*0.29*	*125.3*
25	*23.0*	*0.24*	*169.1*
40	*23.8*	*0.19*	*208.9*

A Mohr-Coulomb failure criteria was computed from the strength data. The best fit to the data is $\tau = 18.1 + \sigma \tan \varphi$, where φ is equal to 39.2°, τ is the shear stress, and σ is the normal stress.

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