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Pore Pressure Coefficient Anisotropy Measurements for Intrinsic and Induced Anisotropy in Sandstone

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Abstract

In this study, we determine experimentally the effect of inherent and stress-induced anisotropy on stiffness components, elastic moduli, and Biot's pore pressure coefficients (PPCs) for Lyons outcrop Colorado sandstone which exhibits a clear transverse isotropic rock structure. Both dynamic and quasi-static methods were used under a non-hydrostatic state of stress to perform the measurements on dry core samples. Our assumption of apparent transverse anisotropy was initially confirmed with acoustic velocity measurements and at a later stage in the loading with experimental transverse anisotropic failure analysis. The objective of this study is to identify and isolate the effect of stress-induced anisotropy from the inherent transverse anisotropy on the measured stiffness components, elastic moduli, and Biot's PPCs. The effect of stress-induced anisotropy appears to have significant control on measured stiffness components, elastic moduli, and Biot's PPCs as compared with the inherent transverse anisotropy effect. Our work shows that the stiffness components, M_{ij}, thus computed elastic moduli, are highly influenced by the stress-induced anisotropy especially the off-diagonal stiffness components, M_{12} and M_{13}, where the increase in their magnitudes from the dynamic measurements prior to failure is determined to be 100% and 81%, respectively. The difference in the magnitude between the axial and lateral Biot's PPCs, in line with bedding planes and perpendicular to them, is measured to be 24% and 16% from the quasi-static and dynamic methods, respectively; whereas, the effect of stress-induced anisotropy reduced the dynamic average magnitude of the Biot's PPCs along the bedding planes and transverse to these planes by 63% over a stress range of 145 MPa.

Introduction

Understanding and isolating the effects of inherent and stress-induced anisotropy on the rock elastic and poroelastic properties is crucial for many engineering applications. In particular, geologists, geophysicists and petroleum engineers are very much aware of their importance for reservoir in-situ stress interpretation, directional drilling through stratified and complex formations, enhanced oil recovery and reservoir stimulation through hydraulic fracturing, and accurate estimation of formation pore pressure prediction. All of these aspects are of paramount importance in oil and gas recovery and field optimization. In most of the above mentioned applications, rock is usually assumed to be isotropic. However, rocks in general exhibit anisotropy due to their mode of deposition, mineral microstructure characteristics, and the presence of various fracture alignment and distribution vis-à-vis the in-situ stress. Anisotropy can also result from complex physical and chemical processes associated with transportation, deposition, compaction, cementation, etc. (Simmons and Wang, 1971; Amadei, 1996). Rocks with properties that vary with direction are called inherently or intrinsically anisotropic. However, when isotropic in-situ rocks undergo large stress perturbation and variations, such as after drilling operations, reservoir formation subsidence, or due to pore pressure depletion, the rock stiffness anisotropy that results from these conditions is termed "stress-induced" anisotropy.

Numerous studies exist on the effect of stress-induced anisotropy on measured rock properties under either uniaxial or hydrostatic state of stress (e.g., King, 1969; Nur and Simmons, 1969; Rai and Hanson, 1987; Vernik and Nur, 1992; Stanchits et al., 2003; Dewhurst and Siggins, 2006). The theoretical aspect of the effect of stress-induced anisotropy on the elastic response of rocks, including sandstone and shales, has also been investigated by many researchers, such as Thomsen