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横向各向同性地层(VTI)井孔声弹效应对弯曲波的影响

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Acoustoelastic effects on flexural waves in a borehole surrounded by a transversely isotropic (VTI) elastic solid

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摘要 本文发展了建立在地层参考状态为各向同性介质假定下的现行井孔声弹性理论,就井外为横向各向同性面与井轴垂直的、具有9个独立三阶弹性模量的横向各向同性介质(VTI井况),水平面内受双轴应力作用下给出了一个简洁的与井内压力、应力差、应力和以及多极源偏振方位角有关的井孔弯曲波声弹公式,并且导出了平面纵、横波速度的声弹公式.数值考察了弯曲波速度之改变量的灵敏系数随频率的变化、受井外水平双轴应力作用时两种偏振的偶极弯曲波频散曲线以及对应不同方位径向偏振的横波速度.研究结果表明弯曲波声弹公式与5个二阶弹性系数以及7个独立的三阶弹性模量有关;而且由内压引起的井孔弯曲波声弹性公式中的三阶弹性模量仅与6个独立的弹性模量有关.横向各向同性介质井孔弯曲波速度的交叉现象仍是判断地应力存在的标志;一个重要的认识是受双轴应力作用的弯曲波速度变化在低频区主要与c_{144}和c_{155}两个三阶弹性模量有关,而且此认识与径向偏振的平面横波一致.在缺乏足够实验条件情况下,对VTI情况,以c_{144},c_{155}和c_{123}三个独立的量进行测量,然后可暂不考虑三阶弹性模量的各向异性,建立简化的应力反演公式.反之,如果已知地层的地应力信息,由简化的声弹公式可以反演三阶弹性模量c_{144},c_{155}和c_{123}.

关键词 井孔, 双轴应力, 声弹性, 横向各向同性, 三阶弹性模量

Abstract: Flexural waves in a fluid-filled pressurized borehole surrounded by a transversely isotropic elastic solid (VTI) with nine independent third-order elastic constants in the presence of biaxial stresses are studied. The acoustoelastic formulations of flexural wave and plane wave are presented. Sensitivity coefficients and velocity dispersions for flexural wave, and shear-waves of radial polarization due to the presence of stresses are numerically investigated, respectively. The acoustoelastic formulation explicitly shows that the velocity dispersions of flexural wave depend on seven independent third-order elastic constants in the presence of biaxial stresses, on six independent third-order elastic constants in the presence of borehole pressurization alone, and on the sum and difference of biaxial stresses and azimuthal angle of dipole source polarization. Numerical results of both sensitivity coefficients and velocities show that at low frequency flexural wave velocity is sensitive to c_{144} and c_{155}. The crossover of dispersion curves of flexural waves implies the presence of abnormal stress. A formulation of inverted stresses by flexural wave velocity may be simplified by omitting the anisotropy of third-order elastic constants. If the stresses are known, third-order elastic constants can be estimated with simplified formulation.

Keywords Borehole, Biaxial stresses, Acoustoelastic, Transversely isotropic elastic solid, Third-order elastic constants

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