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应力松弛对颗粒物质弹性性质的影响及等效介质模型校正研究

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A study of the influence of stress relaxation on the elastic properties of granular materials and the calibration of effective media model

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摘要

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摘要 未固结碎屑砂岩储层是国内外重要的油气储层类型之一,其物理本质是由离散颗粒组成的软凝聚态物质。在地震勘探中通常使用Hertz-Mindlin等效介质模型来计算未固结砂岩的地震弹性特征,但该模型在使用中通常会得到明显偏高的剪切模量值。基于3D离散元技术,对颗粒介质在单轴压缩与纯剪两种过程中的力学响应进行离散元数值模拟,从微观颗粒尺度和细观力链尺度分析等效介质模型产生预测误差的可能机制,结果表明颗粒相对滑动、旋转、重排列等造成的应力松弛作用对体积模量计算结果的影响较弱,但在剪应力扰动下这种松弛作用所形成的细观不均匀应变对剪切模量的计算会有明显影响,是等效介质模型形成预测误差的主要原因。在此基础上给出了利用切向刚度校正因子 C 及组合参数 R 对Hertz-Mindlin等效介质模型进行修正的方法,以考虑颗粒间松弛作用及颗粒不规则性对该模型计算结果的影响,并应用于实际测井资料中验证了方法的正确性。

关键词: 未固结砂岩 颗粒介质 应力松弛 离散元 Hertz-Mindlin接触模型 等效介质模型

Abstract: In seismic exploration, the effective medium theories based on Hertz-Mindlin contact model were often used to predict the seismic elastic properties of unconsolidated sands. But those theories often give larger shear modulus comparing to measured data. By using 3D discrete element simulation, a series of uniaxial compression and pure shear test were carried out on granular material with the aim to study the insufficiencies of those effective medium theories from the level of microscale of particle size and mesoscale of force chain. The simulation indicates that stress relaxation resulting from the rotation and rearrangements of particles has negligible influences on the calculation of bulk modulus. But the stress relaxation has significant influences on the calculation of shear modulus under the shear stress perturbation. Shear stiffness calibration factor (C) and combined parameter R were advocated to calibrate those effective medium theories based on Hertz-Mindlin contact model to accounting for the influence of relaxation in contact area and grain angularity.

Keywords: Unconsolidated sands Granular materials Stress relaxation Discrete element Hertz-Mindlin contact model Effective medium theory

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