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多孔介质流－固－热三场全耦合数学模型及数值模拟

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摘要 给出多孔岩体介质的流－固－热三场全耦合数学模型。假定流体为单相流，固体介质为非沸腾的饱和、热弹性多孔介质，该模型由流体物质守恒方程、力学平衡方程和能量守恒方程这3个相互耦合的方程组成，其中包含了众多耦合项，并定义一系列的本构关系及耦合变量。以FEMLAB工具为基础，将该数学模型转化成为一个统一的偏微分方程组，在人机交互的环境下，实现流－固－热三场全耦合数值求解，一次解出渗流场、位移场和温度场，给出更接近真实物理过程的数值解答，避免松散耦合法求解多场耦合问题带来的误差。利用一个已知解析解和数值解的算例来证明了耦合模型及求解方法的正确性。最后模拟通过井孔向岩体中注入冷水时流－固－热全耦合过程，详细地分析全耦合作用对井壁围岩应力的影响，计算结果表明：流－固－热三场耦合作用对井壁的稳定分析有非常重要的影响。

关键词 岩石力学；多孔介质；流－固－热三场全耦合模型；数值模拟

分类号

FULLY COUPLED THERMO-HYDRO-MECHANICAL MODEL OF SATURATED POROUS MEDIA AND NUMERICAL MODELLING

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Abstract

A fully coupled Thermo-Hydro-Mechanical model is presented in a single-phase，non-boiling linear thermoelastic medium，which incorporates cross-coupled fluid flow equation，energy conservation equation and mechanical equilibrium equation with many cross-coupling terms. A series of constitutive relations and cross-coupling relations between material properties and independent variables are defined in the model. The coupled multiphysics model is simultaneously simulated by using FEMLAB，the first engineering tool that performs partial differential equation-based multiphysics modeling in an interactive environment，which the mathematical model is translated into a set of partial differential equations. The pore pressure，displacements and temperature，which should theoretically approach the most realistic results，can be solved simultaneously by using FEMLAB，in which the errors in other coupling algorithms can be avoided. An example with known analytical and numerical results is used to validate the multiphysics model. In particular，cold water injection into wellbore is modeled with realistic time steps indicating that the coupled processes have significant effects on the stresses of borehole wall and wellbore stability.

Key words rock mechanics；porous medium；fully coupled Thermo-Hydro-Mechanical model；numerical simulation

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