软岩与水相互作用的非线性动力学过程分析

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摘要　 软岩与水相互作用的非线性动力学过程的研究不仅对软岩软化的研究方法具有探索价值，而且对于合理确定软化的参数及其应用具有重要的实践意义。结合东深供水改造工程中灰白色泥质粉砂岩不同饱水时间后的试验数据分析，发现该类软岩的软化具有非线性特点。将时间序列的分维分析方法应用于软岩与水相互作用系统中，通过重建相空间，确定了描述该系统所需的最少变量数。试验中发现，软岩的微观结构、力学参数是反映软岩软化的控制性因素，因而取微结构孔隙分布分维值Ds、粘聚力c和内摩擦角j 值作为描述该系统的3个变量。在此基础上，应用反演分析理论，确定了软岩软化的非线性动力学模型，再将以上3个变量的时间序列值通过求残差平方和极小值的方法与模型进行逼近，得到模型中各个未确定的参数，从而对软岩与水相互作用过程进行非线性动力学分析。结果表明：所给出的非线性动力学模型计算得到的微结构孔隙分布分维值Ds、粘聚力c和内摩擦角j 值与试验获得的相应参数值的分布曲线非常接近，说明软岩与水相互作用具有显著的非线性动力学特点；同时，利用所建立的模型可较好地预测软岩在饱水条件下，一定时间后的微观结构参数和力学性质变化规律。

关键词　 岩石力学；软岩与水相互作用；关联维数；反演分析；非线性动力学

分类号

ANALYSIS OF THE NONLINEAR DYNAMIC PROCESS OF THE INTERACTION BETWEEN SOFT ROCK AND WATER

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Abstract
 The research on the nonlinear dynamic process of the interaction between soft rocks and water has great values for the studying method of softening process；and it also has some practical significances for the determination of softening parameters. Based on the data analysis of the test results of white and grey colored argillaceous siltstone from the Water Supply Reconstruction Project from Dongjiang to Shenzhen in Guangdong Province of China，in different saturation times，it is found that the softening process of this kind of soft rock is provided as nonlinear characteristics. By applying the fractal analysis method of time series to the interaction system of soft rocks and water；the least needed numbers of dimensionalities (i.e.，variable numbers) for the description of the system is determined by rebuilding the phase space. The test research shows that the microstructure，the connecting strength and the

roughness of the grains can be well reflecting the softening features of the saturated soft rocks，and are the key factors for softening process. So，the pore distribution fractal dimension Ds，cohesive force c and internal friction angle j are considered as the necessary variables for the description of the system. And then，the nonlinear dynamic equation of the softening process of the soft rock is established by applying the inverse theory；the undetermined parameters of the equation are obtained by approaching the time series of the three variables to the model by the method of searching for the minimal value of residual sum of squares. Thereby，the nonlinear dynamic process of the interaction between soft rocks and water can be analyzed. The researched results show that the calculated curves of pore distribution fractal dimension of micro-structure，cohesive force c and internal friction angle j of the soft rocks are very close to the test ones，which means that the soft rock-water interaction system has a distinct nonlinear dynamic feature. Meanwhile，the results also show that the model can well predict the varying regularities of microstructure parameters and mechanical properties of saturated soft rocks condition in a certain time scale.

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