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# 破碎岩体中气体渗流的非线性动力学研究

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摘要 在采矿和岩土工程中，破碎岩体中的渗流具有非线性、非稳态及参量时变等特点，外界扰动下渗流参量的渐变易引起渗流系统动力学响应的突变，引发突水及气体突出等动力学灾害。采用非线性分岔及突变理论研究破碎岩体中气体渗流失稳的动力学机制。建立气体一维非稳态、非达西渗流的非线性动力学模型，给出量纲一化后的速度平衡态解图，得到渗流平衡状态的孔隙压力、渗流速度的分布规律，即平衡时沿着渗流方向，各点的量纲一孔隙压力与渗流速度的乘积为一常量，且压力的平方呈线性下降。通过低松弛迭代法给出渗流系统相应于不同渗流参数时的动力学响应。研究结果表明，破碎岩体渗流动力系统存在鞍结分岔，分岔点处破碎岩体的颗粒棱角破碎现象相当显著，渗流处于临界稳定状态，此时对应于任意小的扰动系统都会发生折叠突变，引发突出动力灾害。

关键词 岩石力学；破碎岩体；非达西气体渗流；非线性动力学；鞍结分岔；折叠突变

分类号



# NONLINEAR DYNAMIC STUDY ON GAS FLOW IN BROKEN ROCK MASS

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**Abstract**

In fields of coal mining，geotechnical engineering，the flow in broken rock is nonlinear，instable and time-varying for seepage parameters. Under the external disturbance，the gradual variation of the seepage parameter is apt to result in the catastrophe of the dynamic responses of the flow system and induces disasters such as water inrush and gas outburst. The study of the flow stability on the broken rock mass induced by mining is a basic subject of a series of important research topics such as controlling the stability of the surrounding rock，preventing the outburst disaster，exploiting and using the underground resources. The theories of bifurcation and catastrophe in nonlinear science are used to study the dynamic mechanism of instability of gas flow in broken rock. The nonlinear dynamical equations of one-dimensional non-Darcy and unsteady gas flow in broken rock are established. The solution diagram of dimensionless velocity under steady-state is given and the distribution

laws along the direction of flow are obtained for the pore pressure and the steady-state flow velocity; namely, along the flow direction, the product of the pore pressure and the flow velocity of the dimensionless steady-states is a constant and the square of the pore pressure descends linearly. With low relaxation iteration, the dynamical responses corresponding to the different flow parameters of seepage system are also given. The results indicate that there is a saddle-node bifurcation in dynamic system of flow in broken rock; and at the bifurcation point, the breaking of edges and corners of rock grains is remarkable; thus an arbitrary weak perturbing at this point may result in a fold catastrophe of flow system and induce some dynamic disasters such as gas outburst, etc..

**Key words** rock mechanics; broken rock; non-Darcy gas flow; nonlinear dynamics; saddle-node bifurcation; fold catastrophe

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