文章编号:1003 - 5923(2005)03 - 0003 - 03

管棚注浆法过断层施工中喷孔分析

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摘　要:东欢坨矿 - 500 运输大巷施工中,遇特大断层,首次将管棚注浆法运用到深部巷道的过断层施工中,由于断层破碎带极不稳定,在钻孔过程中出现了喷孔塌孔现象。本文针对这一现象,采用有限差分法分析发生喷孔的原因,从力学角度和位移场两方面来综合进行考虑,给现场施工和设计提供指导。

关键词:管棚注浆;断层;喷孔;数值模拟;FLAC^{3D}
中图分类号:TD322　　**文献标识码**:A

1　工程概况

开滦东欢坨矿业公司 - 500 北运输大巷,由于 F2 断层带破碎夹泥,钻探过程中经常发生塌孔、喷孔(喷出物多为断层泥、岩石碎块及煤粉等),故巷道提前停止掘进,一方面进行探测工作,一方面寻求巷道通过的支护方案。

通过合理分析和考察,煤科总院西安分院决定对该矿 - 500 北运输大巷穿越 F2 断层采用管棚注浆预支护方法。

- 500 北运输大巷底板标高 - 490.8 m,岩性层位为煤 12 - 2 底板粉砂岩～细砂岩。上方距煤 12 - 1 为 12.5 m,下方距煤 12 - 2 为 4 m,煤 12 - 2 底板发育一层砂岩裂隙强含水层。

1.1　地质条件

据 - 500 北运输大巷第 12、13 次和已施工完成的 2 个放水孔钻探资料,结合其他已有的资料综合确定 F2 断层带由三条断层组成,即 F2 - 1′、F2 - 2 和 F2 - 3′。

F2 - 1′～F2 - 2 间有的孔发现岩石破碎,有的孔无明显变化;F2 - 2′～F2 - 3 间岩芯较破碎,出水喷孔,故对 F2 断层带总宽度推测如下:

(1) 主要断层带宽度为 F2 - 2′～F2 - 3 间:14.4 m(巷顶)～26.6 m(巷底),宽 12.2 m。

(2) F2 - 1 断层为主断层之前伴生的小断层,即裂隙造成岩石破碎。

1.2　水文情况

通过 3 次对 F2 断层的探测,过 F2 - 2 断层后均发生出水和喷孔现象,在 F2 - 2′～F2 - 3 断层间,各探测孔水量为 0.33～1.8 m^3/min,测得水压为 2.2 MPa。

2　数值模拟

2.1　问题分析

分析注浆孔钻孔过程发生塌孔喷孔的原因,综合考虑了水压力和高地应力的影响。由于断层带宽度较大,且对两盘岩石存在裂隙水,开钻探测孔后,打破了原来的平衡,使得原不含水的断层开始吸水,断层内填充物遇水后即失去粘结力变为稠状物。在 - 230 回风大巷的施工过程中,曾发生过喷孔伤人等现象。此模拟主要针对外注浆孔钻取过程,观察其周围岩体受力的变化和松散介质的运动方向,以此来间接分析发生塌孔和喷孔的原因。

2.2　模拟思路

模型中建立 5 个注浆孔,首先在水压力和初始地应力的情况下,整个模型达到平衡状态。在钻取注浆孔过程中,由于岩体受扰动,应力重分布,同时引起破碎带的碎石烂泥发生运动,记录其速度大小和运动方向,结合实际情况进行合理分析。

数值模拟分析时,注浆孔的开钻顺序是先进行顶板垂直上方钻孔(3 号孔),根据现场施工情况,钻完即进行注浆加固,钻孔后计算达到平衡,分析其应力和位移的变化及其影响范围,合理改变钻孔周围岩体的属性,并取注浆有效半径为 0.5 m,此即完成 3 号孔的注浆。然后进行 2 号孔的开钻,在 3 号孔已经注浆加固后,对开钻 2 号孔会有一定的影响,依序进行开钻,分析后开钻的孔洞应力和洞围介质的运动变化。

收稿日期:2005 - 05 - 18
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2.3 计算模型

模型大小为 21.2 ×25.5 ×16.4 m, 在 x 方向的范围取 - 10.6～10.6 m,原点取为隧道底板的中部,垂直方向的模型范围为 - 4.4～7 m,隧道轴向取 0～25.5 m,模型所取范围合理,包含了钻孔的影响范围。整个模型的网格见图 1,共划分节点 107042,单元 105120。

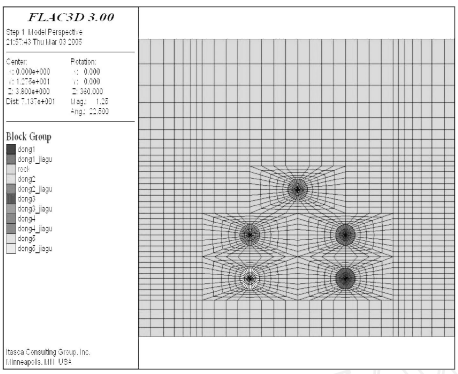

图 1 模型立面网格划分图

2.4 材料物理参数

计算范围内共包含 5 种材质,它们分别是:保护岩柱、伴生断层带、主断层带、注浆加固体以及断层对盘岩层,由于岩石和岩体材料性质不一样,故采用 Hoke - Brown 准则对岩石参数进行折减计算,取值情况见表 1。

2.5 初始地应力

初始地应力在垂直方向按岩体自重考虑,水平应力通过查询东欢坨地质方面的资料,x 方向取为 11.4 MPa,y 方向取为 18.8 MPa,最大主应力方向接近于隧道的轴向,对隧道开挖后的稳定有利。

2.6 水压力

水压力的分布是较关键的问题,根据地质报告,当钻探孔钻至断层 17 m 处,有大量的水及烂泥涌出,且水压为 2.2 MPa,考虑超前探孔破坏了原水分布平衡,使得断层内含水,同时在对盘岩石也存在裂隙水,且水压较大。

表 1 物理参数取值表

岩性	弹性模量 E/ GPa	体积模量 K/ GPa	剪切模量 G/ GPa	摩擦角 f/ (°)	粘聚力 C/ MPa	抗拉强度 R_t/ MPa	泊松比
伴生断层	1.44	0.8	0.6	30	1.8	1.8	0.2
碎裂带	0.225	0.45	0.3	18	0	0	0.125
注浆加固体	0.78	0.45	0.3	35	1.0	1.0	0.23
保护岩柱	1.95	1.0	0.83	35	3.0	3.0	0.17

2.7 单孔开钻模拟分析

首先开钻 3 号孔(最上部),分析单孔开钻过程中的位移、应力的变化情况。模拟的过程是按实际开钻的程序,逐渐向前推进,记录开钻过程中位移、应力及其介质运动的速度随时间的变化曲线图。

(1) 位移分析。开钻过程中,位移的变化是随钻入不断变化的,在保护岩柱段,岩性较好,孔围岩的影响及其变形不大,当钻入断层部分,遇较弱岩层,其破坏范围将明显变大,在此阶段,其位移量也同时增大,位移变化的速度迅速提高。图 2 为围岩在轴向的彩色位移云图,随着接近对盘岩石,位移变化也逐渐减小。计算过程中的记录分析显示,速度的产生很快,可见位移是在短时间内发生的,在 - 500 m 高地应力的情况下就可能发生塌孔现象。

(2) 应力场分析。钻孔破坏了岩石的三向受力平衡,为达到稳定状态,应力要进行重新分布,如某部位出现了较高的应力集中,很容易造成围岩破碎,产生大变形。在本工程中,稳定后的应力分布情况对顺利进行钻孔至关重要。同时,存在水压力使得本工程相对其它一般注浆工程,存在更大的困难。

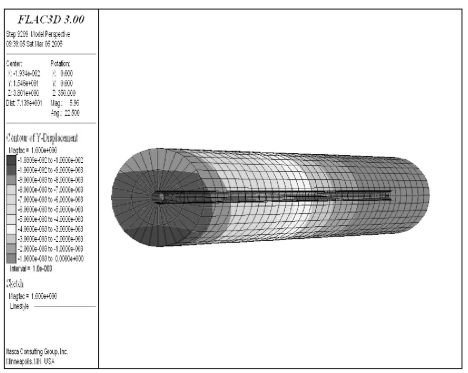

图 2 孔边围岩轴向位移云图

图 3 为孔围岩在钻孔过断层时的 x 向应力分布图,图中明显看出,在孔周边的围岩发生了很高的应力集中现象。x 向应力分布情况是孔径表面应力较低,而孔边围岩达 14 MPa,相对孔径表面应力突然增大了 4 MPa,发生应力集中,随着向岩体深部的延伸,应力则逐渐降低,最后接近原岩应力。由分析可知,在孔边岩体在钻孔过程中的应力重分布中,发生了较大的应力集中现象,加上水压力的存在,当钻头穿透水层,断层填充物被水弱化后,即很易出现喷孔和塌孔的现象,因此,施工现场应做好防喷措施。

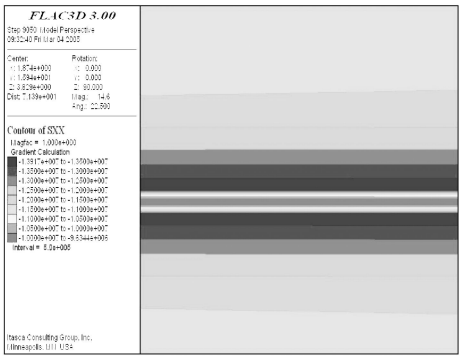

图 3　注浆孔周边围岩 x 向应力分布云图

2.8　五孔开钻模拟

在完成 3 号孔开钻后,立即进行注浆施工,施工完成后即进行下孔的开钻,现在分析五个注浆孔施工完成后的情况,分析其位移及围岩应力的变化情况。

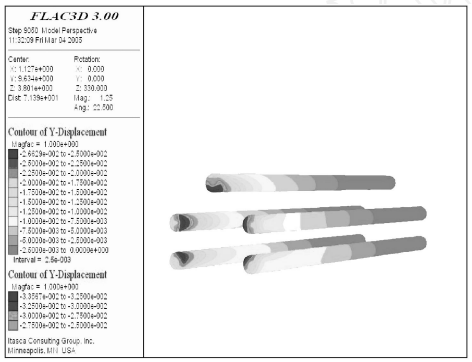

图 4　围岩 y 方向彩色位移云图

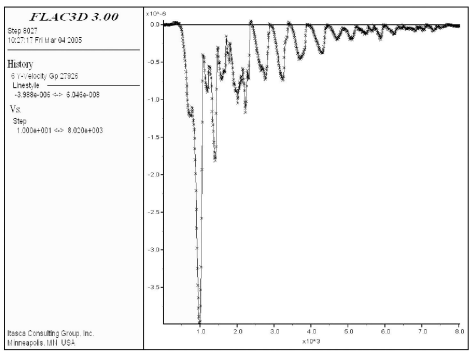

图 5　断层孔边围岩 y 向速度变化曲线图

(1) 位移场分析。注浆加固后,孔围岩在 y 方向产生的位移云图如图 4,从图中可看出,总体的位移量并不大,越接近对盘稳定岩层,位移量逐渐减小,介质向着管棚方向运动,在较高的地应力及水压力作用下,速度由零迅速增加到较大值,由于介质松散且夹带烂泥,易出现喷孔现象,在孔洞 4 的开钻计算过程中,记录了断层中部点的介质的运动速度变化曲线图(图 5),从图中速度的变化曲线图可知,当钻孔到达断层部分时,介质速度迅速提高,随着计算步数的增大,又出现瞬降的现象,可确定主要位移是在短时内发生的,而钻孔工作面是自由面,无任何约束,故介质在高应力的作用下会发生喷孔现象。

(2) 应力场分析。孔径为 150 mm,其影响范围较小。管棚钻孔工作面属自由面,如图 6 所示,红色区表示应力为零,即为自由表面,而在孔面周边产生应力集中现象。它是促使钻孔时发生喷孔和塌孔的主要原因,其不断增加,使孔边围岩受力不断增加,同时断层内介质属性弱化,当超过其承载力,即破坏并沿孔洞喷出,z 向应力最高达 15 MPa。

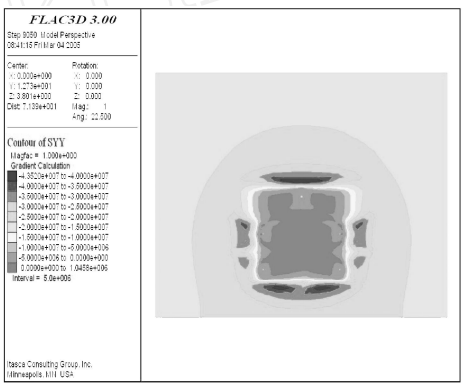

图 6　工作面处轴向应力分布图

3　结论

通过数值模拟计算分析,产生塌孔喷孔破坏的原因为:

(1) 断层带破碎夹泥,其稳定性极弱,在钻孔过程中,扰动了断层,使裂隙水进入断层,造成其进一步的弱化。

(2) 钻孔破坏了原有的三向平衡,使围岩应力发生重新分布,由于巷道位于 - 500 m 处,地应力值较高,使得钻孔周边出现很好的应力集中。

(3) 对盘裂隙水压力的存在,对断层造成影响。其在弱化断层带的同时,更加大了钻孔周边松动圈的压力。

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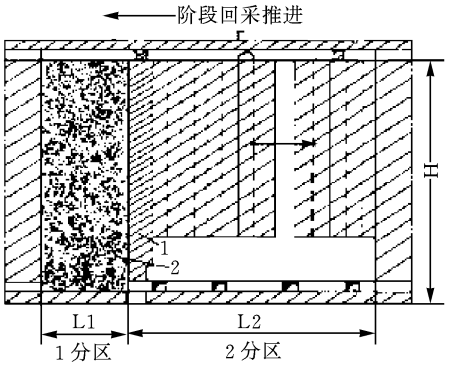

图 3　某铜矿采矿方法图

1 - 临时矿壁;2 - 充填

采试验的成败。在凿岩峒室设矿柱,以支撑峒室顶板。矿段回采顺序为:首先崩落 1 分区内的矿石,出矿后随即充填 1 分区的空区,形成人工隔墙;接下来,除保留临时矿壁外,崩落 2 分区内的其余矿石,待这一部分崩落矿石出矿工作快要结束时,最后一次性崩落临时矿壁;放出 2 分区内被崩落的矿石,用尾砂充填其余空区,结束该矿段的回采作业。

基于凿岩峒室矿柱强度和矿柱应力的计算,可建立矿柱安全系数为:

$$F_s = \sqrt{s\sigma_c^2}\,(0.778 + 0.222\,\frac{w}{h})/\sigma \qquad (11)$$

式中:s 是矿体质量的无量纲常数;σ_c 是矿石单轴抗压强度;w 和 h 分别是矿柱的宽和高;σ 是矿柱的平均垂直应力,用三维有限单元法计算。矿体参数概率特征如表 2 所示。建立如下矿柱极限状态方程:

$$Z = g(X_1, X_2, \wedge, X_n) = F(E, \gamma, \mu, \sigma_c) - 1 \qquad (12)$$

表 2　矿体参数概率特征表

参数	概型	均值	标准差
弹性模量 E/ MPa	正态	63000	15750
容重 γ/ MN ·m^{-3}	正态	0.0328	0.00328
泊松比 μ	正态	0.23	0.0345
抗压强度 σ_c/ MPa	正态	53.0	10.6

以弹性模量、容重、泊松比和抗压强度作为径基函数网络的输入,矿柱的极限状态函数 Z 作为输出,利用三维有限单元法的计算结果,通过学习和训练,建立矿柱极限状态方程或安全系数的径基函数网络,并计算相应的偏导数。计算结果见表 3 (设定在标准正态空间),并与文献[6]对比。可以看出,两者的结果基本一致,说明了本法的实用性。

表 3　变异系数对可靠指标的影响

变异系数	0.10	0.15	0.20	0.25
本文方法	3.40	2.48	1.89	1.58
文献[6]	3.43	2.51	1.94	1.52

5　结论

提出基于径基函数网络、一次二阶矩法和数值分析方法的岩体工程随机可靠度分析新方法。岩体工程极限状态函数及其偏导数用径基函数网络来模拟,然后计算岩体工程极限状态函数的统计矩,求解可靠度和失效概率。通过实例对比研究,说明了新方法的实用性。使用径基函数网络来模拟极限状态函数及其偏导数,具有以下优点:(1) 事先不必假定输入随机变量与输出变量的关系式,而响应面法等需假设 1 次或 2 次多项式;(2) 径基函数网络的映射能力更强,模拟精度更高。

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矿山压力与顶板管理

ENGLISH ABSTRACTS

Supporting technology and unliner macro-deformation phenomenon of soft rock in LiuHai Coal Mine ——HE Man-chao etc.

The paper bases on the repairing project of LiuHai Coal Mine, describing and assaying the unliner macro-deformation phenomenon of the mine, from applying the method, which is turning the involved mechanical mechanism into the single one, expounding the workable and effective supporting countermeasure, ultimately resolving the problem.

The analysis on the spewing failure in the project taking lead pipe grouting to go through the fault ——JIANG Yao-dong etc.

The DongHuanTuo mine transportation roadway meets the fault in the excavation. It is the first time to take the grouting to the tunnel at depth. It needs high technique and excavated method. Drilling arises spewing because of the unstable of rock. This article adopts the numerical simulation to analyse the causation. It is considered from the two aspects of mechanic and displacement, then it can direct the local work.

Study on pump excavation deformation and fracture with complex stress under deep mining and high pressure ——LI Jin-kui etc.

Field measure and analysis on its deformation with complex stress state under high deep mining and high pressure by taking pump excavation of Fengfeng Group Mine Wannian as example. The results show that the deformation of excavation with complex stress state under deep mining and high pressure is visible rheonomic deformation and displacement like soft rock. Its deformation and displacement is irregular one in whole section. The floor heave is main reason to excavation fracture.

Stability analysis on surrounding rock of underground excavations ——YU Wei-ping etc.

Basic methods including finite element analysis of excavation of underground excavations, numerical simulation of anchoring and evaluation criterion of adjacent rock damage zone around excavations are produced in this paper. Graphics system for the visualization of underground chambers' finite element analysis has been developed, based on object-oriented ideology. This system presents an effective tool for analysis results' arrangement of underground cavities and schemes assessment. And it will do good to the shaping of finite element analysis software for underground engineering.

Stability analysis of the construction period for the underground powerhouse ——ZHANG Lian etc.

According to the measured data on the construction period for the underground powerhouse, the mechanical parameters of rockmasses and the initial stress field are validated using nonlinear 2D FEM. On this foundation, the stress distribution and deformation of the surrounding rock mass in the underground powerhouse are analyzed. The influences concerning the sequence of excavation and shotcrete-bolt supporting on the stress and deformation are studied. Finally, the stability of the underground powerhouse and the optimum support and excavation plan is evaluated.

Application of back-propagation artificial neutral net to nondestructive testing of bolt bonding integrity ——ZHOU Li-ming etc.

The theory of BP artificial neutral net is using on testing of bolt bonding integrity. The basic principles and algorithm are also described. The theory is using on the reservoir in HuBei province. Practical example indicates the theory is feasible. The research has improved the method of acoustic frequency stress wave for inspecting nondestructively the construction quality of bolting.

The regularity of electromagnetic emission in roof movement ——DOU Lin-ming etc.

With the advancing of work face, the cracks will be induced and then impenetrate with each other in roof, and result in the rupture of roof and roof weighting. During the process of breach in roof, the phenomenon of electromagnetic emission would be induced. The higher the stress in coal mass is, the fiercer the movement of roof is, the more intense the process of breach is, the greater the electromagnetic signal is. Research shows that there are some evident corresponding relationships between the changes of electromagnetic signals and the time and place when and where the roof above work face ruptures. The development of the motion state of the roof above work face can be concluded with electromagnetic technology, which is a new method of monitoring and forecasting the movement of the roof above work face.

A new mechanical model for soft rock structural surface rheology ——CHEN Yuan-jiang etc.

There are two mechanisms of the coarse surface asperity resistance effect and rubbing resistance effect in the course of the soft rock structural surface creep, the former of which plays a dominant role in hindering the deformation in the starting creep phase and the latter does so when the asperities in the coarse surface fracture by shearing. Under the low stress condition, there are only two phases of the decelerating creep and the constant creep for the soft rock structural surface. As the stress increases so that it can overcome the rubbing resistance, the accelerating creep failure of the structural surface will happen suddenly. In order to describing the creep characteristics comprehensively, the paper brought forward a new multiple rheological model by combining the nonlinear Newton body (NN) of a certain mass and the experiential plastic body (EM) with the classical St. V body (S), Newton body (N), Kelvin body (K) and Hooke body (H). The correlative computation and analysis showed that the model could reflect the actual creep course of the soft rock structural surface so that it could be popularly used in engineering practice.

An elastoplastic model of the rock nonlinear unified strength theory ——ZAN Yue-wen etc.

Using the unified manner to flow vector corner singularity, the flow vector expressions for yield (or failure) surface of the Rock Nonlinear Unified Strength Theory are derived in this paper. According to these expressions, a computer program block on the elastoplastic material model of the Rock Nonlinear Unified Strength Theory can be written and applied to the finite element analysis software. As an yield function, the Nonlinear Unified Strength Theory can be applied to the numerical computation of rock engineering.

The design research and application of hydro-jacking test system ——LIU Yuan-kun etc.

The authors and their research team design a set of bran-new hydro-jacking test equipment and suited software on the basis of their hydro-fracture research. The equipment and the software have been applied in an international project and the results are sound and confirmed by the international experts.

Structural countermeasure and optimum design of surface construction in the ground subsidence area ——HAN Xue etc.

In the process of the feasibility study of the surface construction in the ground subsidence area, the method combined with geophysical exploration and drilling is applied to obtain the characteristics of subsidence strata. By stress analysis and stress ratio critical depth analysis of the above rock strata in ground subsidence area, the rational building density and building height are selected. According to the different design projects, the different construction countermeasures are made, which can provide experiences for other analogous engineering constructions.

Stability analysis for position block of underground powerhouse in the THREE GORGES ——HUANG Zheng-jia etc.

The stability for position block of the underground powerhouse in the Three Gorges Project is one of the key problems for the project design. Applying block theory and soft, the geometrical characteristic value of 6 position blocks is computed. And the block stability safe factor is studied under different design condition. The block stability is assessed after reinforcement.

Technique of triaxial geostress survey in deep rockmass ——ZHONG Zuo-wu etc.

The geostress survey using the hollow inclusion triaxial strain gauge has many outstanding merits over others. This measuring method has been widely used both at home and abroad. But this measuring method was adopted in shallow horizontal borehole before. The technique of geostress survey in deep borehole adopting this kind of strain gauge is introduced in this paper. Its measuring depth has reached 365m, it is the maximum depth in the stress relief measuring methods in our country.

Research on chaos of deformation of cemented tailings backfill in deep mining ——LIU Zhi-xiang etc.

The maximum yield strains of backfill specimen with different cement-tailing ratios being tested, and the deformations of high backfill in deep mining being monitored, the stability of high backfill was researched on chaotic theory. Reconstructing phase space to measured data, the intrinsic laws of deformation of different backfill were researched. According to monitored data, the chaotic attractors of deformation of backfill with different cement-tailing ratios and their maximum Lyapunov exponents were calculated, and their deformations were predicted with maximum Lyapunov exponents, as well as a reasonable period in high-level deep mining in Anqing copper mine was analyzed. Research results show that the deformations of backfill hold the character of chaos, and chaotic theory is propitious to research their characters of deformation and breakage, e. g. the lower the cement-tailings ratio, the higher the fractal dimensions and maximum Lyapunov exponents of deformation will be.