

李大伟 著

深井与软岩巷道二次支护原理及控制技术

PRINCIPLE AND TECHNOLOGY OF DOUBLE SUPPORTS
FOR ROADWAY IN DEEP MINE AND SOFT ROCK



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内 容 提 要

本书通过理论研究和现场多种支护方式的对比试验,建立了一次锚杆支护弹塑性,大刚度高强度二次支护巷道黏弹、黏塑性力学模型,进行了深井软岩巷道一次锚杆支护、二次大刚度高强度支护围岩稳定控制的理论计算与应用分析,确定了二次大刚度高强度支护的合理参数,试验选择了安全可靠的支护方法。

本书可作为高等院校采矿工程、地下工程等专业研究生的教学参考书,对从事隧道及巷道支护或现场管理的科研人员和工程技术人员也具有一定的参考价值。

前 言

深井、软岩巷道问题多，支护难度大，严重影响煤矿的安全和正常生产。制约深井巷道支护技术发展的瓶颈问题依然是支护理论和合理围岩稳定控制技术的研究。深井、软岩巷道二次支护围岩稳定的原理多停留在定性讨论、分析阶段，尚未进行较深入的理论计算分析，深井、软岩巷道的控制方法缺少有效的理论指导。

在多年的研究中，笔者对深井、软岩巷道大刚度高强度二次支护围岩稳定原理进行了深入研究，计算确定了合理的一次支护、二次支护的参数，试验选择了大变形巷道安全可靠的支护方式。具体采用的研究方法及得到的结论如下：

(1) 从围岩应变软化巷道弹塑性力学计算出发，用锚杆两端对围岩体内锚固区施加的两组夹紧力来考虑锚杆支护对巷道围岩应力状态改变的影响，并引入软化模量与非关联流动法则，建立了锚杆支护对围岩稳定作用的弹塑性力学模型，得到了不同锚固区半径时的围岩应力、巷道位移的理论计算公式。

(2) 应用黏弹-黏塑性力学理论，建立了深井、软岩巷道一次支护弹塑性和大刚度高强度二次支护黏弹、黏塑性力学模型，经计算得出了二次支护最大工作阻力值的黏弹、黏塑性理论解析解；分析了二次支护前后围岩体应力状态的变化结果；依据理论方程进行了二次支护参数的确定，使得二次支护的选择更

具有针对性。

(3) 采用 FLAC 数值模拟软件分析了一次锚杆支护的围岩体应力分布及大刚度高强度二次支护前后围岩体的应力状态变化情况。研究结果证明一次锚杆支护模型、围岩流变二次大刚度高强度支护模型的建立是科学合理的。

通过理论分析及数值模拟得出的结论，在低强度软岩巷道进行了大变形围岩稳定控制试验，分析了各种支护方式的效果。结果表明，二次锚网喷索支护难以控制巷道围岩的持续变形，“一次锚网喷+二次大刚度高强度支护”控制低强度软岩巷道是科学合理的。

综上所述，深井、软岩巷道大变形围岩稳定控制的原理可简要概括为：一次支护让压围岩体受力达到较低变形速率下的力学平衡，可充分发挥围岩承载力；二次大刚度高强度支护，可使巷道周边围岩不处于瞬时强度高承载位置的应力状态，也可避免围岩的再次应变软化与蠕变导致的状态恶化、岩体承载力降低，对减少巷道围岩体偏应力、促进围岩应力向长期强度和稳定转化有显著作用。

由于笔者理论水平及实践经验所限，书中难免会有不足甚至谬误之处，请各位专家、学者和广大读者批评指正。

著 者

2008 年 8 月

Foreword

There are many problems in support of the deep mine and soft rock roadway. Support of the roadway is difficult, and seriously affect mine security and normal production. The theory study seriously restricts support technique development of deep mine and soft rock roadway. Double supports principle is general qualitative discussion and analysis, and selection of support mode lacks effective theory guidance.

This book mainly studied surrounding rock stability principle of double supports with great rigidity and high strength for deep mine and soft rock roadway, calculated the first and second rational support parameters, tested and selected safe and reliable support mode for large deformation roadway.

The elastic and plastic mechanics model of surrounding rock stability action for bolt support was established, in which the strain softening modulus and non - associated flow rule were introduced, the support effect on rock - mass stress state changing was represented by two group of compression forces at bolt anchor district of surrounding rock, C and φ of the rock were not changed. Through calculation, the stress distribution of surrounding rock, roadway perimeter displacement u_0 , strain softening district radius R_p , and broken district

radius R_t of the rock – mass were formulated for various support strength q and anchor district radius R_m , and their change tendency was analysed. The formulations were applied selecting bolt support parameter in mine testing roadway. The mathematical analysis solution of elastic and plastic mechanics on surrounding rock provided a basis for the quantity design on bolt support roadway.

The stress distribution of surrounding rock for bolt support roadway has a fall – down on the radial line, on which radial stress σ_r decreases a values of qR_0/R_m , and circumferential stress σ_θ decreases 2 ~ 3 times value of qR_0/R_m when bolt anchor end is in the plastic district, decreases 1/3 ~ 1 times qR_0/R_m when bolt anchor end is in the elastic district. The u_0 , R_p , R_t assume function relations with R_m when R_m increasing in initial stage, and basically have not a change after a stage. Under the same support strength q condition, the u_0 , R_p decrease when q increasing, whose the absolute values of relation curve gradient are larger at begin while q value is lower, and less while higher. The bracket support is less than bolt support in plasticity district radius and displacement of roadway surrounding rock.

The mechanics model of the surrounding rock stability principle of double supports for deep mine and soft rock roadway was established, applying viscoelastic and viscoplastic mechanics theory. The model is elastic and plastic in the first support stage, and viscoelastic and viscoplastic in the second support stage. The analysis solution of viscoelastic and viscoplastic for the double supports roadway was calculated, and changing results of stress state for surrounding rock were

analysed before and after the second support. The double supports parameters were determined with theory equation, and mode choice of double supports was correct.

The work resistance of double supports with large rigidity and high strength is a passive balance force. It increases with the occurrence and development of rheologic deformation, compensates the part of stress reduction in the surrounding rock rheologic deformation, and assures rock - mass stress changing to stability stress state and rock - mass rheologic deformation gradually weakening, when surrounding rock has not new displacement. The largest work resistance of double supports with large rigidity and high strength increases with the work resistance strength q of first support increasing in a rational range, when original stress, bolt length of the first support, and mechanics property of surrounding rock are definite.

The surrounding rock stress distribution of bolt support, and the stress state change of surrounding rock were calculated, and analysed with FLAC before and after large rigidity high strength double supports. The research result of numerical value calculation proved that the first bolt support model and double supports model with large rigidity and high strength were scientific and reasonable.

Through test and calculation of controlling surrounding rock stability on deep mine and soft rock roadway with large deformation, the experiment results of various support modes were analyzed. It was concluded that the double supports of bolts, meshes, jetting concrete, anchor ropes could not control the lasting deformation of surrounding

rock. , and the first bolts, meshes, jetting concrete and the second support with large rigidity and high strength was scientific to control the surrounding rock stability.

The mechanism of surrounding rock stability on deep mine and soft rock roadway with large deformation is summarized as follows. The first support releases pressure, fully uses support action of the surrounding rock, and makes force balance of the rock be at low deformation rate. The second support promotes the rock - mass stress changing to long - term strength and stable state of stopping rheologic deformation, avoids the surrounding rock of roadway perimeter is under stress state of the momentary strength and reduction of rock - mass capacity in creep and new strain softening, decreases rock - mass circumferential stress, increases radial stress, and optimizes stress state.

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