超大断面隧道软弱破碎围岩渐进破坏过程三维地质力学模型试验研究

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3D GEOMECHANICAL MODEL FOR PROGRESSIVE FAILURE PROGRESS OF WEAK BROKEN SURROUNDING ROCK IN SUPER LARGE SECTION TUNNEL

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摘要 为研究超大断面隧道围岩随埋深逐渐增加的渐进性破坏过程，通过大型三维均匀梯度加载地质力学模型试验系统和软弱破碎围岩及其支护系统相似材料的研制，开展大跨度隧道围岩随埋深逐渐增加渐进破坏过程的大比尺模型试验，真实再现全断面和台阶法开挖段周边围岩及掌子面保留段软弱破碎围岩渐进破坏的全过程。首先，以一定范围内埋深(200～1 020 m)的双线大跨度隧道软弱破碎围岩(铁路隧道V级)为研究对象，采用铁晶粉、松香、石英砂、重晶石粉以及聚四氟乙烯棒等原料研制出具有应变软化特性的软弱破碎围岩、初喷混凝土以及锚杆等相似材料，并配以能实现精细开挖和支护施作的微型设备及其配套工艺，通过可实现三面均匀同步加载的大型三维地质力学模型试验台架模拟隧道全断面和台阶法施工的全过程，并采用光纤光栅传感器、电阻式应变计、多点位移计以及微型压力盒全程监测隧道洞壁及其整数倍洞径(0～3倍)范围内围岩的应力、位移以及近区荷载的变化信息；然后，对隧道全断面和台阶法开挖段以及掌子面保留段围岩进行超载试验，按50 m埋深等荷加载改变隧道埋深，直至隧道全断面无支护段围岩开始出现明显破裂特征，然后再按20 m埋深等荷加载缓慢增加隧道埋深，直至隧道全断面和台阶法支护段初喷混凝土大面积破坏脱落。试验结果表明：(1) 在埋深不断增加过程中，隧道围岩破坏区域呈渐进扩大趋势，全断面无支护段周边围岩最早发生破坏，然后依次扩展至全断面支护段初喷混凝土和台阶法支护段初喷混凝土，最终破坏区面积顺次由大到小；(2) 无支护段围岩破坏区和支护段衬砌结构破坏区均主要集中在拱顶上方区域，是衬砌结构破坏和围岩塌落荷载的主要来源，两侧边墙也存在局部破坏区，自边墙上部至拱角部位破坏程度逐渐加剧；(3) 在埋深增加过程中，支护段围岩位移增长率小于无支护段，应力和荷载增长率恰相反，支护结构承载效应明显；(4) 超载过程中，围岩的破坏深度不断增加，尤其是拱部呈现动态压力拱现象，据此确定顶部加固范围在理论上具有可行性。研究的方法技术及结果将对类似工程研究具有一定的指导和借鉴意义。

关键词： 隧道工程 超大断面隧道 软弱破碎围岩 渐进破坏过程 模型试验 演变规律

Abstract： To investigate the progressive failure progress of rock mass with increase of buried depth in super section tunnel，a 3D geomechanical model test system with homogeneous gradient loading and similar material of weak broken surrounding rock and support system were developed. Then the 3D model test was carried out which showed the progressive failure progress of weak broken surrounding rock of entire section method and bench method. Firstly，the weak broken surrounding rock in a range of 200－1 020 m in depth was taken as an example. The strain softening behavior of weak broken surrounding rock and shotcrete can be simulated by different proportion mixtures of iron powder，quartz sand，barite powder and rosin alcohol solutions. Polytef sticks can be used to simulate the bolts. Besides，combining the micro-devices of excavation and construction supporting the construction progress of entire section method and bench method can be well simulated by the 3D model. In addition，the changing information of stresses，displacements and loads in the scope of entire times of the tunnel diameter(0－3 times) can be monitored by fiber grating sensors，resistance strain gauge，multipoint extensometer and micro pressure cells. Secondly，an overloading test was carried out after the end of excavation. The loading gradient was 50 m on the direction of the burial depth until the significant failure characteristics occurred in the no supporting sections. Then the loading gradient was changed to 20 m until the initial shotcrete damaged in large areas. The test results show：(1) The failure zones of rock masses expand with the increase of the burial depth. The no supporting sections fail earliest. Then the failure zones extend to the supporting sections. And the final areas of failure zones decrease gradually. (2) The failure zones of rock masses of no supporting sections and the liner failure zones of supporting sections mainly focus on the crown which is the load sources of the liner failure and the collapse of the surrounding rock. There also exist failure zones on the side walls. The degree of damage increases from the upper part of the side wall to the skewback. (3) The growth rate of displacements in supporting sections is smaller than that in no supporting sections with the increase of burial depth. However，the growth rate of stresses and loads are just opposite. The supporting structures burden the loads obviously. (4) The failure depth of surrounding rocks increase continually in the overloading test. The dynamic pressure arching phenomenon occurs in the scope of crown. Hence，the top reinforcement theory is feasible in theory. The research methods and results will instruct similar engineering.

Keywords： tunnelling engineering super large section tunnel weak broken surrounding rock progressive failure progress model test evolution law