COUNTERMEASURES FOR STABILITY CONTROL OF DEEP UNDERGROUND OPENINGS THROUGH FAULT ZONES IN ARGILLACEOUS ROCK

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論文題名 ：COUNTERMEASURES FOR STABILITY CONTROL OF DEEP UNDERGROUND OPENINGS THROUGH FAULT ZONES IN ARGILLACEOUS ROCK （泥質岩盤中の断層破砕帯を通過する深部主要坑道の安定性制御対策に関する研究）

区　　分　：甲

論 文 内 容 の 要 旨

Faults are complex geological conditions commonly encountered during underground excavation. It is also usual to encounter argillaceous rock when constructing an underground opening. Geological conditions will be more complicated and stability control is more difficult when deep underground openings have to pass through fault zones in argillaceous rock due to the limitation of engineering project routes. Instability of underground openings triggered by faults is often irrecoverable and sometimes catastrophic. Moreover, delayed deformation and failure of underground openings in argillaceous rock can occur several years after excavation, which undermines long-term stability. The stability of deep underground openings in operation determines the sustainable safety production of underground coal mines. Therefore, study on the construction safety and stability control of deep underground openings through fault zones in argillaceous rock is of great theoretical significance and practical engineering significance to deep underground coal mines, as well as other deep underground excavations with complex geological conditions. Based on the construction safety and stability problems of an 800-m-deep underground opening encountering geo-hazards through fault zones in argillaceous rock in the Guqiao Coal Mine in East China, certain research methods were undertaken. Field geological survey, pilot industrial tests, laboratory experiments, numerical simulation, theoretical analysis and field measurements were comprehensively adopted to analyze the deformation and failure characteristics of the surrounding rock, reveal factors influencing safe excavation and structural stability, analyze the influence of a fault on a deep underground opening and study proposed control techniques for safe excavation and stability.

This dissertation consists of seven chapters, as described in the following.

Chapter 1: This chapter introduces the research background and significance. The safety and stability control problems of deep underground openings through fault zones in argillaceous rock are stated based on previous research and current problems in deep underground coal mines in East China. The research contents, objective, approach and outline are described. The main objectives are to propose safe excavation and stability control techniques for deep underground openings through fault zones in argillaceous rock.

Chapter 2: The engineering geological conditions in the targeted underground coal mine were investigated, tested and analyzed by field geological survey, 3D seismic exploration, X-ray diffraction (XRD), argillization experiment, uniaxial compressive strength experiment and field measurements. At first, it is found that a fault group with a maximum combined throw of 140 m is 670 m long from north to south. The influence scope of the geological anomaly fault zones is approximately 720 m long in the tunneling axis direction. XRD and argillization experiments show the argillaceous rock is composed of over 70% water sensitive clay minerals, including kaolinite, illite, smectite and illite-smectite interstratified minerals, etc. These materials are hydrophilic swelling soft rock and are sensitive to disintegrating and weathering, which indicates shotcrete and grouting should be applied in time to seal the rock surface to inhibit weathering processes after excavation. The deep underground opening is located in an extremely high-stress area. The values of the maximum, the minimum horizontal and vertical principal stress are 28.78, 16.34 and 18.08 MPa, respectively. The in-situ stress field is dominated by horizontal tectonic stress. The engineering rock mass classification ranks category V, which can be badly broken and soft without self-stability after excavation, which indicates pre-reinforcement is necessary.

Chapter 3: This chapter analyzes the deformation and failure mechanism of deep underground openings through fault zones in argillaceous rock. Pilot industrial tests, field measurements, theoretical analysis and numerical simulation were carried out to analyze the deformation, failure characteristics and influence factors of the surrounding rock. According to the field study, it was found that cable anchoring and cement post-grouting performance in fault zones in argillaceous rock are extremely poor. It was also found that deformations and failure of the surrounding rock are characterized by dramatic initial deformation, high long-term creep rate, obviously asymmetric deformation failure and support pressure, rebound of roof displacements, large-scale loosening of deep surrounding rock and a high sensitivity to engineering disturbance and water invasion. Numerical simulation indicates the displacements quickly increase when the distance from the center of the fault fracture zone is 5 m. The displacements reach the maximum in the center of the fault fracture zone, and then decrease as the tunneling face gradually moves away from the fault fracture zone.

Chapter 4: This chapter proposes concerted control techniques for safe excavation and the stability of deep underground openings through fault zones in argillaceous rock. These techniques include improving regional lithology, e.g., ground surface pre-grouting (GSPG), initial stability control measures of surrounding rock and secondary enclosed annular support for the long-term stability. The theoretical calculation of the grouting pressure for GSPG by hydraulic fracturing method provides a valuable guidance for GSPG practice. The minimum final pump pressure should be more than 6 MPa when GSPG is conducted at a depth of around 800 m in the targeted underground coal mine. The corresponding minimum grouting pressure at the borehole bottom is around 20 MPa, that is, 2.5 times as big as the hydrostatic pressure at a depth of 800 m. Pre-grouting should be carried out and deep holes post-grouting with chemical material should be made in time to decrease the permeability, i.e., block fracture water from seeping, prevent the argillaceous rock from argillization, improve the strength and the stability of argillaceous rock and improve the cable anchoring performance. Chemical grouting is particularly important for the stability of deep underground openings in fractured argillaceous rock mass with rich groundwater.

Chapter 5: Based on engineering geological conditions in the targeted underground coal mine and stability control techniques proposed in the previous chapters, the stability of deep underground openings by different support schemes in fractured rock mass is analyzed to optimize support parameters by means of Universal Distinct Element Code (UDEC) software. The numerical results show that the concerted scheme including 8-m-deep holes grouting around the whole section, U-shaped steel sets, bolts and long cables for the full cross-section can generally control the deformations of surrounding rock mass ranking Category V under the condition that the fault fracture zone is filled by GSPG. The floor reinforcement is very important for the stability of the deep underground opening in fractured rock mass.

Chapter 6: This chapter puts forward a GSPG scheme for the proposed 800-m-deep underground opening through fault zones for the first time and support schemes of re-excavation based on the results of successful pilot excavation and numerical simulation. Fluctuation response and deformation features of surrounding rock during GSPG, and ground pressure and deformations during re-excavation are analyzed based on field measurements. From this observation, it is found that the impact of GSPG on the stability of the 800-m-deep underground opening dramatically decreases as the distance from the grouting borehole increases. The influence distance is up to 137 m along the opening axis, which indicates that the safe distance during GSPG should be more than 137 m. The correlation of the maximum deformation velocity and the distance from the grouting borehole is obtained based on the monitoring data. Quality assessment of grouting by experiment and re-excavation verification indicates that GSPG not only achieves the effect of blocking water-bearing conduits and eliminating groundwater inrush risk, but also improves the regional engineering rock mass stability and ensures construction safety. Compared with the displacements during the pilot excavation, the displacements are greatly reduced during re-excavation.

Chapter 7: Principal conclusions and innovation points abstracted from the discussion are summarized.