ESTABLISHMENT OF SUBSIDENCE MODEL CONSIDERING LONG-TERM BEHAVIOR OF CAVING ZONE IN LONGWALL COAL MINE

孟, 凡非

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氏　　名：　孟　凡非

論文題名：　ESTABLISHMENT OF SUBSIDENCE MODEL CONSIDERING LONG-TERM BEHAVIOR OF CAVING ZONE IN LONGWALL COAL MINE (長壁式採炭法を用いた坑内掘り石炭鉱山における Caving Zone の長期挙動を考慮した地盤沈下予測モデルの確立に関する研究)

区　　分：甲

論　文　内　容　の　要　旨

Ground subsidence in underground coal mining areas causes environmental damage and creates hazards on the ground surface, which is long-term, widely distributed, and can lead to large-scale geological disasters. Achieving a high-precision method to predict mining subsidence deformation is very important for assessing environmental damage and identifying countermeasures. The longwall mining system is a very productive and efficient method and is widely used throughout the world as a coal mining technique. During longwall mining, the immediate roof caves in behind the hydraulic shield support as coal is continuously extracted and then overlying strata hangs up to form a rock beam. As the longwall face continually advances, the rock beam breaks into large blocks and then collapses when the span reaches a certain limiting value. The broken rock fills in the gob area in a space termed a caving zone. The overburden strata can be divided into three vertical zones including the continuous deformation zone, the damage zone, and the caving zone. Brillouin optical time-domain reflectometer (BOTDR) technology is introduced and adopted in this study to obtain the movement data along the vertical direction above the gob. According to the results of the field measurements, the deformation of the caving zone is the most complex, and the long-term behavior has not yet been clarified. Therefore, this research discusses the deformation mechanism and long-term behavior of the caving zone by means of field investigations, laboratory tests and numerical simulations. This dissertation consists of seven chapters and the main contents in each chapter are listed as follows:

Chapter 1: This chapter introduces the research background and significance of prediction of the long-term behavior of the caving zone in order to predict long-term surface subsidence due to the longwall coal mining operation. The reviews of the literatures on the measurement technology and prediction of surface subsidence and ground behavior were also presented in this chapter. This chapter describes the objectives of this research.

Chapter 2: The chapter describes the BOTDR technology for measurement of ground movement due to longwall coal mining operation. As the BOTDR technology can measure the strain at specific monitoring points, the returned strain is somewhat different from the rock mass strain outside of the monitoring point. Hence, in case that the strain data returned from the monitoring point is considered the same as the overall deformation of the rock, a large cumulative error will occur, especially in the caving zone and the damage zone. The new calculation model which can calculate the ground deformation above the gob based on the data measured by BOTDR technology is proposed. In this model, the ground above the gob is divided into three zones: the caving zone, the damage zone and the continuous deformation zone then the constitutive model of each zone is developed. The caving zone is represented as the constitutive model of rock fragments. The deformation of this model contains the compressive deformation of the rock body and the sliding behavior among rock particles. The damage zone represents the fractures zones as an elastoplastic body. The continuous deformation zone represents the elastic deformation zone and unconsolidated zone which can be modeled as the elastic body. The amount of surface subsidence above the gob can be calculated by the summation of deformation of each zone.

Chapter 3: In order to discuss the applicability of BOTDR Technology, the long-term behavior of each zone and the applicability of calculation models proposed in Chapter 2, the field investigation and the analysis of measurement data is conducted in Zhangzhuang coal mine, Anhui Province, China. Based on the measurement data, it is confirmed that the overburden can be classified into three zones: the continuous deformation zone, the damage zone, and the caving zone in terms of the deformation behavior. Large strain can be observed in the caving zone and it increases with increasing elapsed time after extraction of longwall panels. Additionally, as a result of predicting the deformation in each zone using the calculation model proposed in this research, the long-term deformation behaviors of the damage and continuous deformation zones can be simulated. However, the long-term deformation behavior of the caving zone cannot be simulated and it is remarkable differences between the predicted value and measured one. Hence, it can be said that the long-term deformation behavior of the caving zone has to be understood and modeled in order to predict long-term ground behavior due to the longwall coal extraction.

Chapter 4: In order to understand the long-term deformation behavior of the caving zone, a series of triaxial creep tests are conducted using the specimen that simulates the caving zone filled with rock fragments under different axial pressures, confining pressures and size distributions of rock fragments. Based on the results of a series of creep tests, it can be said that both the axial and confining pressures have an obvious impact on the creep behaviors of the specimen. The creep strain increases with increasing the axial pressure and decreases with increasing the confining pressure. Moreover, it also can be recognized that the breakage of rock fragments inside of the specimen occur during creep tests and this phenomenon also has an obvious effect on the creep behavior of the specimen. Here, the relative breakage index, which is calculated by the total breakage volume divided by the total volume of rock fragments, is introduced in order to evaluate the breakage degree of rock fragments in the specimen. The size of rock fragments in the specimen has an obvious impact on the breakage behavior of rocks and the breakage index become large when the contents of large size rock fragments is large. In addition, as the breakage index increases with increasing confining pressure, it can be expected that the decrease of creep strain with increasing confining pressure is due to the internal structural change of the specimen. Therefore, it can be said that the bulking coefficient, which represents the characteristics of volume expansion, is an important factor for prediction of long-term deformation behavior of the caving zone.

Chapter 5: The bulking coefficient plays an important role for long-term deformation behavior of the caving zone. In order to understand the long-term deformation behavior and determine the bulking coefficient of the specimen that simulates the caving zone, a three-dimensional numerical model of the specimen is developed and simulated by means of Particle Flow Code (PFC) Ver. 5.0. The failure criterion of the rock fragments in the specimen is also implemented in this simulation. Based on the results of a series of numerical simulations, the deformation behavior of the specimen can be understood and the creep behaviour of the specimen can be simulated by Burgers creep model. Moreover, as the particle size distribution of rock fragments in the specimen, the axial and confining pressures have an obvious impact on the bulking coefficient of the specimen, the deformation characteristics parameter which represents the effects of the particle size distribution of rock fragments in the specimen, axial and confining pressures on the bulking coefficient is determined and introduced. Then the bulking coefficient under different conditions and elapsed time can be predicted.

Chapter 6: In this chapter, a new creep model is proposed in order to predict long-term behavior of the caving zone considering the change of bulking coefficient of caving zone. The new model attempts to predict the long-term behavior of the caving zone by incorporating the deformation characteristics parameter into the transition creep factor in the Burgers creep model. Compared with the results of the triaxial compressive tests, it can be said that the new creep model can simulate the behavior of the specimen simulated caving zone more accurately than the classic Burgers model. Moreover, compared with the results of laboratory tests with excavation model and the field measurement data of the caving zone in Zhangzhuang coal mine, it can be verified that the new proposed model can predict the long-term deformation behavior of the caving zone.

Chapter 7: This chapter summarizes and concludes the results and findings of this research.