（様式２）

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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 the caving zone. The overburden strata can be divided into three vertical zones including a continuous deformation zone, a fractured zone, and caving zone from the top to the bottom. Brillouin optical time-domain reflectometer (BOTDR) technology was introduced and adopted in this study to obtain the movement data along the vertical direction of the overburden, which can also provide information about the height of each zone. According to the results of the subsidence in each zone in the field study, the deformation of the caving zone was the most complex, and the long-term behavior has not yet been clarified. Therefore, this research discussed the deformation mechanism and long-term behavior of 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 are 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 may be somewhat different from the rock mass surrounding the monitoring point. Hence, it can be expected that a large cumulative error may occur if the strain measured by BOTDR technology at the monitoring point is considered to be the same as overall deformation of the rock mass, especially in caving zones and damage zones. The new calculation model which can calculate the ground deformation above gob can be calculated from the data measured by BOTDR technology is proposed. In this model, the ground above the gob is divided into three zones: caving zone, damage zone and continuous deformation zone then the constitutive model of each zone is developed. The caving zone is represented as the constitutive model of broken rock mass. The deformation of this model contains the compressive deformation of the rock body and the sliding behavior of 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 value of surface subsidence above gob can be calculated by the summation of deformation of each zone.

Chapter 3: In order to discuss the applicability of BOTDR Technology and identify the technical issues to be solved for measurement and prediction of long-term behavior of ground movement and surface subsidence due to longwall coal mining extraction, the field investigation was conducted in Zhangzhuang coal mine, Anhui Province, China. Based on the measurement data, it was confirmed that the overburden can be classified into three zones: Continuous Deformation Zone, Fracture Zone, and Caving Zone in terms of the deformation behavior. Obvious strain can be observed in the caving zone which increases with increasing elapsed time after extraction of longwall panels. Additionally, the settlement rate of the caving zone also increases with increasing elapsed time after extraction of longwall panels, and continuous settlement rate of the caving zone also increases with increased elapsed time even though the settlement rates of fracture zone and continuous zone such as unconsolidated and bending zones increase gradually in the beginning and then become stable over time. Therefore, it can be said that the behavior of caving zone has an obvious impact on the long-term ground behavior and subsidence due to the longwall mining extraction. Moreover, comparing with the measurement data of the deformation of each zone, the new calculation model can represent the deformation behaviors of fracture zones and continuous deformation zone. However, the deformation of caving zone cannot be precisely represented and there is still about 10% error between the calculated value based on the strain data obtained by BOTDR Technology and the actual measurement value of surface subsidence. It can be expected that this is because the long-term behavior of the caving zone is not modeled exactly in the calculation model. Hence, 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 were conducted using a specimen composed of grading rocks under different grading sizes, confining stress and axial stress. Based on the results of a series of creep tests, it can be said that both the axial stress and confining stress have an obvious impact on the creep behaviors of the specimen. Moreover, it also can be seen that the breakage of rocks 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 was calculated by the total breakage volume divided by the breakage potential, was introduced in order to evaluate the breakage degree of rocks in the specimen. The grading size of rocks 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 rocks in the specimen is large. In addition, the breakage index increases with increasing confining pressure. Therefore, it can be said that the decrease of creep strain with increasing confining pressure is due to the internal structural change of the specimen.

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 caving zone, a three-dimensional numerical model of the specimen composed of grained rocks was developed and simulated by means of Particle Flow Code (PFC) Ver. 5.0. In this simulation, the damage criterion of the rocks in the specimen by particle discrete element was also implemented. Based on the results of a series of numerical simulations, the deformation behavior of the specimen composed of grained rocks can be understood and the creep behaviour of the specimen can be simulated by Burgers creep model. Moreover, as the particle size distribution of grained rocks, the axial and confining pressures have an obvious impact on the bulking coefficient of the specimen, the deformation characteristics parameter which represent the effects of Talbot index, axial and confining pressures on the bulking coefficient is determined and introduced. Then the bulking coefficient under different condition and elapsed time can be predicted.

Chapter 6: In this chapter, a new creep model based on the fractional order theory is proposed in order to predict long-term behavior of the caving zone considering the change of bulking coefficient of broken rocks. Compared with the result of the triaxial compressive experiments, it can be said that the new creep model can simulate the behavior of the specimen with broken rocks more accurately than the classic Burgers model. Moreover, compared with the results of laboratory excavation tests and the field measurement of the caving zone in Zhangzhuang coal mine, it can be verified that the new proposed model can predict the long-term behavior of the caving zone on a real scale.

Chapter 7: This chapter summarized and concluded the results and findings of this study.