Study on Modeling of Seismic Wave and Gas Permeability Characteristics through Porous Layers in Goaf

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区　　分　：　甲

論　文　内　容　の　要　旨

The large amount of underground coal excavations have caused about 430 million-m^3 goaf widely distributed in China. Goaf is an area that partially or wholly filled with waste and the collapsed rock mass from roof. The monitoring of the goaf properties is important, because the goaf-induced hazards are various with a potential threaten role to the mining operation and natural environment. The seismic method is an effective tool to detect goaf properties. However, in most of the previous investigations using with seismic velocity and attenuation in the goaf areas, goafs were treated as a homogeneous medium and the optimal seismic frequency was not considered against actual rock mass sizes. The characteristics such as porosity, stiffness of discontinuities, size of voids and fragments in the goaf area have not been clearly related to the seismic data, and a model to estimate gas permeability in the goaf also has not been established based on the seismic properties.

In the present study, laboratory measurements were done using porous samples compressing rock particles to construct the new model equations for seismic attenuation and gas permeability consisting porosity, ratio of seismic wave length to particle size, and mechanical properties to apply for a field measurement in underground coal mine area. Furthermore, the quantitative damage by earthquake on the ground surface have been simulated to clear the effect of the goaf on the seismic response.

The dissertation is composed of six chapters as follows:

Chapter 1: This chapter describes a potential inducing hazards by the existence of goaf in the underground strata and provides a background on the detection technologies of goaf field in coal mine areas. Furthermore, this chapter reviews in-situ investigations and theoretical approaches about the seismic and permeability characteristics of goaf presented by previous researches. The research objectives and thesis structures are also described in this chapter.

Chapter 2: This chapter elaborates the measurement apparatuses and methodologies of the seismic and gas permeability in the laboratory. The preparation processes of intact rocks and porous samples compressing rock particles were described. Firstly, elastic modulus, porosity-effective relationship, mineral composition as well as the microstructure of three types of intact rocks, limestone, sandstone and bituminous coal, were measured as basic seismic data to compare the porous rock samples. Three intact rocks were crushed and sieved into particles with three group sizes of 0.12-0.25 mm, 0.25-0.5 mm and 0.5-1.0 mm. Those particles were used to form 135 porous specimens that were pressed in a cylindrical PVC pipe surrounded by a stainless socket using a hydraulic compression press. The porosities of the specimens were controlled to be 0.21 to 0.33 with stepwise compressive process and stress, because seismic property and gas permeability are very sensitive to the porosity. The seismic velocity and attenuation through the specimens were measured by wave frequency from 24 to 500 kHz. The permeability (k) was also measured with same porous specimens used for seismic measurements. The seismic attenuation and elastic velocity changes in rock/coal with different porosities, the effect of particle size (D) and seismic wavelength (λ) were deeply investigated.

Chapter 3: This chapter describes a new seismic attenuation model (the B-R model) based on the multi-fractured rock attenuation model. The B-R model accounts for (i) greater attenuation through fragmented rock due to increased contact points between the particles, and (ii) decreased attenuation caused by network propagating through the porous media. The B-R model was applied to the laboratory measurement results of ultrasonic wave attenuation using compressed porous rock and coal samples, and good agreements were found for various porosities, particle sizes and wavelength. The relationship between porosity and elastic velocity change was closer to that of the B-R model compared with the empirical relation. The B-R model showed better agreement with measurement results when λ/D varied between 65 and 80, which covers most of the λ/D range expected at a coal mine goaf.

Chapter 4: This chapter describes the results of permeability of the porous samples. The results showed that the measured permeability conformed to the corrected Kozney-Carman equation with percolation threshold porosity of 0.06, tortuosity 5–10 and power 4 on porosity. It was cleared that the permeability of porous samples can be expressed with a new model equation combining average square value of particle sizes and two functions defined for seismic velocity change and attenuation. The estimated permeability by the model equation showed a good agreement with the measured permeability data. The permeability of the actual goaf in coal mine was estimated to be $k = 10^7 - 10^9$ md based on compressive stress, rock mass size and properties in the goaf.

Chapter 5: This chapter describes seismic damping coefficient input for the simulator to investigate earthquake wave propagation through the gaof area. The variation of the elastic modulus of goaf material with time was also explained. Various simulations models were established considering the depth, porosity, compaction time as well as the varied damping coefficient. The numerical simulation results showed that the peak ground acceleration (PGA) above the goaf area is reduced because of the presence of goaf. The PGA above goaf is gradually increased with the increasing depth and compaction time of goaf. However, peak ground displacement (PGD) above goaf is increased as the reduction of depth and compaction time of goaf. Especially, the PGD above a shallow goaf 100m from the surface is amplified 2 to 7 times compared with that of the free-field condition. Additionally, the resonant period of the response acceleration spectrum above goaf is around 0.2s longer than that of the places above undisturbed coal-seams.

Chapter 6: This chapter presents the conclusions of this study including the seismic and permeability properties of goaf areas as well as the application of the established models for the estimation of permeability and earthquake damage in the underground coal mine field scale.