（様式２）

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論文題名： EVALUATION OF STABILITY AND ITS COUNTERMEASURES OF UNDERGROUND LONGWALL COAL MINE UNDER SHALLOW AND WEAK GEOLOGICAL CONDITIONS IN INDONESIA (インドネシアにおける浅所の軟弱地山を対象とした長壁式採炭システムを用いた坑内掘り石炭鉱山の安定性評価およびその対策に関する研究)

区　　分：甲

論 文 内 容 の 要 旨

Indonesia is one of the largest coal producers and exporters in the world. The coal production of Indonesia has increased significantly in recent years. In Indonesia, the coal is mainly produced from the surface mines. Recently, the conditions of surface mines have worsened every year because stripping ratio has increased due to the increase in mining depth. The resource of high quality coal located in accessible areas has decreased due to the rapid expansion of coal production. Moreover, the development of a new surface mines is constrained due to its environmental impacts and protection law. Therefore, in order to meet the increased demands of the coal, underground coal mines have to be developed in Indonesia. According to the experiences of underground coal mining in Indonesia, due to the coal measure rocks becoming very weak and the design guidelines of underground mining under weak geological conditions not being developed, ground control issues have occurred frequently. As a result, some underground coal mines have been abandoned. From these backgrounds, the purpose of this research is to investigate ground behavior in underground longwall coal mine under weak geological conditions and to develop its appropriate design guideline. To accomplish the purpose of this research, The PT Gerbang Daya Mandiri (GDM) coal mine in Indonesia and the coal is planned to be extracted by the fully-mechanized longwall mining method, was chosen as the representative mine site. This dissertation consists of five chapters and the main contents in each chapter are listed as follows:

Chapter 1: This chapter introduced the background and geotechnical issues that commonly occurred in the underground coal mines in Indonesia. The reviews of the literatures on longwall mining technology and aspects that affect its stability with a few histories obtained from past longwall mining works were also presented in this chapter. This chapter included an outline and objectives of this dissertation.

Chapter 2: Stability of gate-entry is one of the first considerations for the development of longwall panels. Since there are two major factors influencing the stability of gate-entry in two different stages which are the longwall panel development and its extraction, an adequate support system has to be applied in order to maintain the gate-entry for both stages. This chapter discussed the stability and appropriate design of gate road support for the longwall trial panel located between 100 m and 150 m depth by means of the finite differential software of FLAC3D. As a claystone laid on a coal seam is very weak, even weaker than the coal seam itself, the effect of remaining coal at the top and bottom of gate roads was also examined in order to increase the stability of the gate road. Based on a series of numerical simulations, the coal seam remained in the roof and floor of the gate road helps to increase the stability of the gate road and the optimum thickness of the remaining coal is around 1 m both on the roof and the floor. During gate road development, the gate road can be maintained by the application of steel arch (SS540) with 1 m spacing when the stress ratio is less than 1.5. However, when the stress ratio is larger than 1.5, the spacing of the steel arch has to be changed from 1 m to 0.5 m or additional support has to be installed. During the panel extraction, as the coal seam with 3 m height is extracted, the stress is redistributed into the surrounding area and the high-stress concentration can be observed at the end of the gate road near the longwall face. Especially, the distance from the longwall face is less than 10 m, the stress affecting the support becomes larger than its capacity. Hence, additional supports such as cribs and/or props have to be installed in the gate road according to the face advancing. Besides, the shape of cross section of gate road also has an obvious impact on its stability, and a semi-circle shape is recommended instead of a flat horseshoe shape in case where the depth of the longwall panel has a greater than 200 m.

Chapter 3: This chapter discussed the stability and appropriate support design of gate roads in the main production panels. There are two major key aspects that influence the stability of gate roads in the main panel including the effects of adjacent panels and multi seams extractions. As a result of a series of numerical simulations in the case of adjacent panels, the width of the chain pillar which is the coal pillar left between the adjacent longwall panels should be larger than 50 m in order to minimize the effect of adjacent panel extraction and maintain the stability of the gate road when the size of extraction panel is 130 m in width, 300 m in length and 3 m in height. The mining depth and the stress ratio have obvious impacts on the stability of gate roads. In cases that the depth is 100 m and/or 200 m with a stress ratio less than 1.5, the gate road can be maintained with 1.0 m spacing of steel arches. Besides, in cases that the depth is 200m with a stress ratio from 1.5 to 2.0 and/or the depth is 300 m with a stress ratio less than 1.5, the gate road can be maintained with 0.5 m spacing of steel arches. At a depth of 300 m and a stress ratio is larger than 1.5, the additional supports such as the rock bolts have to be installed. Moreover, the floor heave becomes more severe with increasing the depth and the counter measures such as dinting and/or installation of wooden or fiber bolt has to be applied. In order to understand the seam interaction on the stability of gate roads in multi-seam mining, another series of numerical simulations had been carried out. It can be found that the upper seam extraction has an obvious impact on the stability of gate roads in the lower panel when the distance between the upper panel and the lower one is less than 50 m. In the case that the upper panel is located at 150 m depth and the distance between the upper panel and the lower one is less than 50m, the spacing of steel arch has to be changed from 1.0 m to 0.5 m. Considering the other aspect of mine design such as a mineable coal seam, coal grade, seam depth, etc., if the short distance between the upper panel and the lower one cannot be avoidable, stronger support is required.

Chapter 4: This chapter discussed the stability and control measures of a longwall face under weak geological conditions. The stability of a longwall face is very crucial during panel extraction as it allows the cutting operation to work smoothly and safely. Important factors for the stability of a longwall face are the selection and the control of shield support. There are several criteria for the selection of appropriate shield support and these criteria include in-situ stress condition, canopy ratio, leg pressure. A series of numerical simulations had been conducted in order to discuss the effects of these parameters on the stability of longwall face. It can be seen that the fracture zone is formed around the canopy tip and the stability of longwall face decreases with decreasing stress ratio and the fracture zone becomes more severe after the cutting web. In case that the stress ratio is 0.5, the risk of roof fall and/or collapse of longwall face is very high. So, the installation of dowel to the longwall face has to be conducted in order to improve the stability of longwall face and the roof. It can be also found that the roof caving behavior is different with different stress ratios. The roof caving behavior in the longwall face can be divided into two types based on the condition of stress ratio. When the stress ratio is lower than 1, a roof caving behavior follows the detached block model. On the other hand, when the stress ratio is larger than 1, a roof caving behavior follows the bulking model. A canopy ratio which is the ratio of the length between the tip of the canopy and the connecting point of leg to that between the rear end of canopy and the connecting point of leg influences the load distributions along the canopy. A canopy ratio of 2 is preferred for reducing the fracture zone on the roof, especially for the shallower depth where the rock is relatively weak. Based on the relationship between the leg load and the size of fracture zone developed around the face and roof, it can be said that the setting load at the beginning of the loading cycle should be set as low as 6,000 kN. The selection criteria included a canopy ratio of 2, setting load of at least 6,000 kN with a yield load of at least 10,000 kN as well as the shield configuration that allow 0.25 m of face to tip of the canopy with the cutting web width of 0.5 m.

Chapter 5: This chapter summarized and concluded the key results and findings of the research.