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論文題名：STABILITY CONTROL MEASURES FOR CROWN PILLAR IN CUT AND FILL UNDERGROUND GOLD MINE UNDER PROTECTED FOREST AREA, INDONESIA (インドネシア森林保護区域における充填式採掘法を用いた坑内掘り金鉱山のクラウンピラーの最適設計と安定性制御対策に関する研究)

区　　分：甲

論　文　内　容　の　要　旨

When a conflict of interest between the needs to promote economic development and to preserve environmental conditions arises in the area of natural resources development such as protected forest, the underground mining method might be a solution to maximize benefit from natural resources development while keep maintaining environmental constraints. Indonesia, as one of the countries with the largest area of protected forest and mineralization found under protected forest, has permitted underground mining operations under protected forests with strict regulations. One of its strict regulations is prohibition of subsidence to occur at the surface of protected forests. To avoid subsidence, the use of the underground mining method with filling such as cut and fill is highly recommended. However, several subsidence cases in the application of this method have been recorded. The cause is collapse of stope at shallow depth during excavation. When a stope at a shallow depth collapses, failure may continue until the rock mass separates the uppermost stope with the surface, which is called the crown pillar. Increasing crown pillar thickness could be a way to prevent surface subsidence. However, part of the crown pillar in the cut and fill mining method, which is directly above the stope, is formed by an ore body. Increasing its thickness will increase its stability while also reducing mining recovery since higher volumes of ore body are left behind as a pillar. Therefore, preventing stope failure during excavation is the key to preventing subsidence as well as maintaining stability and optimizing recovery of the crown pillar. An attempt has been made to investigate stope stability in the crown pillar area of the cut and fill mining method by means of Phase2 and FLAC3D. Various countermeasures have been proposed to suit different mine conditions. The results were elaborated in six chapters as follows:

Chapter 1: This chapter gives perspective of the cut and fill mining method application in protected forests. The overview of two cut and fill variants, which are overhand and underhand, was given, stressing some points of their advantages and disadvantages. The overview was followed by the cases of subsidence at application of cut and fill as background of research. The outline and objectives of the dissertation can be found in this chapter.

Chapter 2: This chapter describes the effect of extraction of a stope in the cut and fill mining method under different mine conditions. Two different variants of cut and fill were simulated by means of numerical analysis to evaluate ground behavior and stress condition of its stope and crown pillar. It is found that the underhand cut and fill method gives a better stability condition than the overhand one. Further investigation was carried out in order to learn the stability of the stope and crown pillar at the overhand variant in different mine conditions. The results suggest that crown pillar failure is more likely to occur at cut and fill mines in the lower vein dip, wider vein width, weaker geological condition, and higher stress ratio. Moreover, the simulation of the overhand with different filling material has concluded that properties of filling material have no obvious impacts on the stability of the stope and crown pillar. The results in this chapter highlight the necessity of an appropriate support system around the stope and crown pillar, and other countermeasures in order to stabilize the stope and crown pillar in various mine conditions.

Chapter 3: This chapter reveals the effectiveness of a support system for maintaining the stability of the stope and crown pillar in different mine conditions. Two types of support systems, which are active and passive types, were simulated to stabilize the stope and crown pillar. The result shows the active type support system is not effective for supporting stopes in case the ratio of a horizontal stress to a vertical stress is larger than 1.0 because the large failure zone is developed in the roof. Therefore, the passive type support should also be installed in the stopes in order to maintain the stability of stope and crown pillar if the stope is excavated at high horizontal stress conditions. In general, more supporting capacity of both types of support system is needed if the stope is excavated in more severe geological conditions, lower vein dips and wider vein widths. The direction of the active type support in the wall of the stope has an influence on crown pillar stability, especially in a hanging wall. The results of a series of numerical simulations show that rock support is proven to be effective to support stopes and also crown pillar in various mine conditions. Moreover, crown pillar recovery can be maximized by applying a combination of both passive and active type supports. However, a thick crown pillar still needs to be spared to prevent crown pillar failure that may cause subsidence.

Chapter 4: This chapter introduces the application of sill pillar as countermeasures for stability of the stopes as well as maximizing crown pillar recovery. The sill pillar can be applied by abandoning the uppermost unstable slice from the simulation of stopes supported by rock mass as a pillar. Extraction of ore will be continued above the abandoned slice. The application was simulated at several conditions where it was found that the crown pillar supported by the support system in Chapter 3 is not optimum. Results in this chapter show that the application of sill pillar is very effective to stabilize stopes as well as to increase crown pillar recovery. One of its effective utilizations is to maximize crown pillar recovery of models with a stress ratio of 2 where it can minimize a 20 m thickness of crown pillar into 5 m by leaving a 5 m thickness of sill pillar at 15-20 m in depth. The application of sill pillar can not only improve the stability of stopes but also increase the ore recovery near the surface. In general, the main purpose of the application of sill pillar is to reduce the accumulation of induced stress due to the extraction of ore affected around the stope and crown pillar. There is a possibility to optimize the sill pillar as well by reducing the sill pillar to a stope thickness ratio. However, the sill pillar may yield and the floor of the stope above it will be damaged in some cases. Monitoring during extraction of stope needs to be carried out, and if floor heave and damage is founded, remedial measures need to be taken, for example the installation of concrete in the floor. Moreover, it is also found that the sill pillar can also be extracted by applying a stronger filling material such as cement, and the recovery can be increased. After the stope above the sill pillar is filled with stronger material, the sill pillar can be extracted. However, the cost of fill needs to be considered when such a technique is applied. Therefore, this technique is acceptable only when the ore grade is relatively high. The application of sill pillar not only can improve the stability of crown pillar but also may increase ore recovery by applying the stronger filling material. Therefore, the application of sill pillar is very suitable for overhand cut and fill mines where the ore grade is not so high. Nevertheless, the application of sill pillar in mines with high grade ore will result in some portion of high grade ore left behind as a pillar.

Chapter 5: This chapter introduces the application of the grouting technique as an alternative countermeasure for stability of the crown pillar. When the ore grade is high, there will be availability to apply more expensive countermeasures to increase ore recovery. As the thickness of crown pillar decreases and the stope progressing upwards in the overhand cut and fill, the stope will be located in a shallower depth. As this condition, large subsidence due to failure of the crown pillar and large deformation around the stope can be expected. So, the application of the grounding technique was proposed in order to stabilize thinner crown pillar and control ground behavior. Since ore veins bearing gold rock mass consist of quartz, which has a small porosity, improvement by the injection of grouting material is mainly caused by infiltration of joints within vein rock mass. This effect of grout injection of rock mass properties was represented by improvement of mechanical properties of rock mass. From the results of a series of numerical simulations, it can be seen that the injection of grouting material from the surface is effective to improve the stability of crown pillar and control subsidence. As grouting material is injected into the crown pillar with a 10 m depth from the surface, the thickness of crown pillar can be decreased from 10 m to 5 m without any large subsidence, and then the ore recovery can be increased. However, the grouting method can only be applied if the ore grade is quite high and it is also allowed by the government through environmental impact analysis to inject grouting material near surfaces of protected forests. Simulation with reduction of surface grout area was carried out to investigate the possibility to minimize its impact at surfaces of protected forests. The results show that there is a possibility to reduce the grout area by giving a spacing or reducing grouting radius while the same optimum thickness of crown pillar is maintained.

Chapter 6: This chapter concludes the results of this research.