氏　　名： Seelae Phaisopha（シーラエ　ファイソファ）

論文題名：APPROPRIATE STOPE DESIGN WITH CONSIDERATION OF FRACTURED ROCK MASS WHEN TRANSITIONING FROM OPEN PIT MINING TO UNDERGROUND MINING FOR SEPON COPPER-GOLD MINE DEPOSIT, LAOS（ラオス・セポン銅金鉱山における露天採掘から坑内採掘移行時の破砕性岩盤を考慮した採掘空洞の最適設計）

区　　分：甲

論　文　内　容　の　要　旨

Laos, which is located in the interior of the Indochina Peninsula in Southeast Asia, is rich in mineral resources such as antimony, tin, and copper, as well as silver, lead, zinc, and gold. Although the country has rich mineral resources, it has not been fully developed due to the lack of transportation infrastructure. The Ministry of Energy and Mines of Laos is working to attract foreign investment and promote the mining sector in order to utilize these valuable resources. The Sepon Gold and Copper Operation, a representative mine in Laos, commenced in 2002 and has an average grade of 2.0% copper and 1.8 g/t gold. Since 2014, the production and processing has focused on copper due to a decrease of gold reserves. However, as metal prices rose, the production and processing of gold ore resumed in June 2020 after 6 and half years of production stoppage. In addition, in order to increase the production and cope with the increasing stripping ratio, the development of underground mines from the bottom of the open pit has been considered. The mining plan for this mine when it transitions to underground mining will adopt the overhand open stoping method, which is applied in case the steep vein deposits are present in solid country rock and the extracted ore can be easily transported. However, based on the results of further exploration of this mine that had been conducted as the metal prices increased, it was revealed that the state of the ore deposits targeted for operation has changed significantly and the country rock mass that contains the ores has been fragmented heavily. In addition, as the strength of the ground in shallow areas is low, in order to maintain the stability of the stopes and prevent the surface subsidence due to the underground mining operation, not only do plenty of supports have to be installed but also a large amount of ore has to be preserved as sill and/or crown pillars. Therefore, an optimal design of both pillars and stability control measures are essential in order to maintain the stability of the stopes and extract the ore as much as possible while controlling surface subsidence. Based on the above background, this research discussed the optimal design of the stopes and the stability control measures for mined out areas, considering the fractured rock mass during the transition from open pit mining to underground mining for the Sepon Gold and Copper Operation in Laos. This dissertation consists of five chapters. The main contents in each chapter are listed as follows:

Chapter 1: This chapter describes the outline and current situation of the Sepon Gold and Copper Operation including the geological and topographical conditions and the features of the open stoping method. Then, it discusses the factors to be considered when transitioning from open pit mining to underground mining, as well as the issues in terms of rock engineering.

Chapter 2: This chapter describes the geological features of the area targeted in this research. From the results of a geological survey, it can be found that the mining area currently in operation is a

skarn-type deposit in which copper-gold ore is embedded in jasperoid, calcareous shale, and dolomitic shale. The average dip and thickness of the ore body are 60 degrees and 20 m, respectively. Although the country rock exhibits moderate strength, the dip of the ore body has changed significantly due to folding. In addition, it has a complex geological structure with many faults, and the ground near the surface has been fractured due to weathering, so it is necessary to take these factors into account when developing an appropriate underground mining plan.

Chapter 3: This chapter discusses whether the overhand or underhand open stoping method is appropriate for the target area in terms of the condition of ore deposits such as mechanical properties and fracture conditions of the rock mass when transitioning from open pit mining to underground mining by means of the finite element software, RS2. In this research, the Geological Strength Index (GSI) is used for representing the fracture condition of rock mass. In order to evaluate the effects of the extraction by applying the open stoping method on the stability of stopes and crown pillars under various geological formations and mining conditions, a series of numerical analyses were conducted under different conditions such as the GSI varying from 35 to 50, the dip of ore body varying from 40 to 90 degrees, the stope width varying from 10 to 20 m, the stress ratio which represents the ratio of the horizontal stress to the vertical one varying from 0.5 to 3.0, and the crown pillar thickness varying from 10 to 50 m. It can be found from these results that the stabilities of the stope and crown pillar when an underhand open stoping method is applied is lower than the overhand open stoping method, and the overhand stoping method is suitable for this mine. It can also be found that the smaller the dip of the ore body and the wider the stope, the more the stability of the crown pillar decreases, and the greater the stress ratio, the more remarkable the decrease is. In particular, it is clarified that when the stress ratio is 1.5 or more, it is necessary to leave a crown pillar with a thickness of 40 to 50 m to significantly decrease recovery.

Chapter 4: This chapter discusses the applicability of the overhand open stoping method to gently dipping ore bodies and its countermeasures since the dip of the ore body targeted in this research varies greatly from steep to gentle. Concerning the GSI of the ore body, the hanging wall and footwall are 50, 60, and 70, respectively, and the dip of the ore body is 37 degrees, once the open stoping method with a stope of 10 m width and 25 m height and a sill pillar of 10 m width between neighboring stopes is applied, the underground mining operation has an obvious impact on the stability of the open pit slope and surface. In such a case, it can be concluded that it is difficult to apply the overhand open stoping method, and the mining method has to be changed into the cut-and-fill stoping method with a 10-m or wider sill pillar in order to maintain the stability of the open pit slope and surface sufficiently.

Chapter 5: This chapter concludes the results of this dissertation.