学 位 論 文 内 容 の 要 旨

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学 位 論 文 題 名

Effects of Weak Rock Zones and Stone Wall on Mining-induced Deformation of Rock Slope at Mt. Buko

(武甲山の残壁の掘削変位に与える弱層の影響と盛石の効果)

Unexplained rock slope deformation has been observed at the limestone quarry of Mt. Buko in Saitama Prefecture, Japan, since the automated polar system (APS) was introduced in the quarry. The rock slope in the western part shows significant and continuous deformation although little deformation has been observed in the eastern part. To restrain this continuous deformation, the construction of a stone wall was initiated on the west side. Ensuring the safety of the rock slope requires not only understanding the deformation mechanism but also evaluating the stone wall's effectiveness, which remains an urgent issue.

Vertical and inclined weak rock zones were found through the quarry. The vertical one is developed in limestone deposit, and the inclined one is distributed along the geological boundary between bedrock and the cover rock, which is unexcavated limestone layer for the protection of the base rock against weathering. Understanding the impacts of these weak rock zones is expected to be key to clarifying the mechanism of rock slope deformation, as the connectivity of the two weak rock zones on the west side differs from that on the east side.

Based on the aforementioned background, this study analyzed the deformation characteristics of the rock slope at Mt. Buko, focusing on the relationships among geological structures, excavation states, and field measurement data. Numerical models incorporating the quarry's geological features were developed to estimate mining-induced deformation of the rock slope, aiming to better understand deformation mechanisms. Both the constructed and planned stone walls at the quarry were also numerically modeled to evaluate their mechanical impacts and estimate their optimal dimensions. Furthermore, simplified numerical models were created to assess the effects of the geometry and dimensions of the weak rock zones, providing a generalized understanding of their influence. The effectiveness of general countermeasures, including the stone wall, was also examined using simplified numerical models.

The specific contents of each chapter are as follows:

Chapter 1 systematically describes the background, objectives, novelty, and importance of this study, along with a literature review of related research.

Chapter 2 outlines the deformation issues, geological structures, mining history, and monitoring systems at Mt. Buko. The relationships between the characteristics of the rock slope deformation, the connectivity of the weak rock zones, and excavation progression were analyzed. The results show that

rock slope displacement on the west side accelerates as the vertical weak rock zone (VZ) appears on the rock slope surface with the lowering of the excavation face. This finding emphasizes the importance of accurately modeling geological structures and excavation progress in analyzing deformation mechanisms.

Chapter 3 presents numerical simulations of mining-induced deformation of the rock slope at Mt. Buko, with results that quantitatively align with field measurements. The models indicate the followings. A reduction in normal stress due to excavation leads to progressive failure along the geological boundary. Then, sliding force induced by the boundary failure applies to the VZ behind it. As the VZ appears on the rock slope surface, resistance against the sliding force decreases. Sliding movement stops as the excavation progresses, eventually reaching equilibrium. Thus, the observed continuous deformation is effectively explained by the proposed mechanism.

Chapter 4 numerically analyzes the general effects of dip angle and connectivity of weak rock zones using simplified models by categorizing the features of weak rock zones often seen in open-pit mines. The results indicate that sliding occurs only when two weak rock zones are connected, and sliding movement tends to increase with a reduction in thickness and Young's modulus of cover rock.

Chapter 5 evaluates the effectiveness of the constructed stone wall at the quarry through numerical simulation, highlighting its role in restraining slip deformation. The results reveal that the density of the stone wall significantly influences the restraint of slip deformation, while Young's modulus and Poisson's ratio have little impact. Additionally, optimal dimensions for the stone wall were recommended for future construction.

Chapter 6 examines the effects of width, height, and construction timing of stone walls using simplified models. The findings show that earlier construction, especially at higher elevations, provides maximum deformation control. The results also indicate that the stone wall should be constructed up to the inclined discontinuity, including the geological boundary, as the stone wall helps prevent shear failure along the discontinuities. Additionally, the effectiveness of another countermeasure-reducing the excavation bench width-was also demonstrated.

Chapter 7 summarizes the main conclusions and recommendations of this study. A more in-depth analysis of the stone walls is necessary, as the effect of contact stiffness between the stone wall and the slope remain unclear. The lack of consideration for pore water pressure effects and three-dimensional factors are key limitations that could significantly impact slope stability.