学 位 論 文 内 容 の 要 旨

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学 位 論 文 題 名

Field Measurement and Numerical Analysis of Long-term Deformation of Rock Slope at Higashi-shikagoe Limestone Qaurry, Japan
(東鹿越鉱山における岩盤斜面の長期変位計測と数値解析)

A massive rock slope of about 250 m height, intersected by 70-m-thick clay-bearing rock at its foot wall, has been formed at the Higashi-shikagoe limestone quarry, and has experienced slope failures four times. Consequently, behavior of the rock slope has been monitored by measuring surface displacement along the rock slope with an automated polar system (APS) since 2002. In this study, the mechanism of long-term deformation of the rock slope observed at the quarry was investigated using field measurement and numerical analysis.

The relative displacement at 18 mirror points for more than seven years was analyzed to clear deformation characteristics of the rock slope. It was found that the distance between the beam generator and each mirrors revealed a continuous rate of gradual decrease. It was also found that forward movement of the rock slope toward the southern side of the quarry is the dominant component of the displacement vectors.

Thus, the main cause of the observed continuous deformation was evaluated using two-dimensional (2-D) finite element method. Firstly, the effects of limestone excavation at foot wall of the rock slope, the deterioration of the 70-m-thick clay-bearing rock distributed at foot of the rock slope, and shear failure of rock mass due to water infiltration on the slope displacement were investigated. It was found that the calculated results of rock slope displacement induced by deterioration of the existing layer of clay-bearing rock qualitatively agreed with measured results at the north- side and center of the quarry. However, the magnitude of the calculated displacements is significantly smaller than that of measured displacements. This implied that the rock slope at the quarry is likely not deformed mainly by deterioration of the clay-bearing rock. The results also reveal that the rock slope displacement at south- side of the quarry is mainly caused by excavation at the floor wall if the horizontal stress is sufficiently large. To clarify effect of the existing layer of clay-bearing rock on the slope displacement, elasto-plastic analysis was carried out. Again, it was found that displacement induced by excavation is quite significant if clay-bearing rock behaves as an elasto-plastic material and the horizontal stress is large enough.

Three-dimensional (3-D) elastic analysis was proposed to evaluate the effect of regional stress arising from mining on the rock slope deformation. At first, three 3-D meshes of different model sizes were generated to clear the effect of boundary conditions. The results show that model with a size of four times larger than that of the mining area is large enough for simulation. Subsequently, regional stress state and Young’s modulus were estimated by back analysis of mining-induced deformation. The findings are as follows; (a) the estimated stress state of the quarry is almost uniaxial compression with

the maximum principal stress range of -2.10 to -2.62 MPa, (b) the magnitude and direction of regional stress is independent of Young's modulus of the existing layer of clay-bearing rock, (c) estimated Young's modulus of 4.57 GPa by back analysis is close to that estimated by GSI, and (d) the direction, N21° W of the estimated maximum principal stress is close to that of measured stress, N18° W. Thus, the stress state in the quarry could also be influenced by regional stress due to tectonic activity. Finally, to interpret mining-induced deformation from 2014 to 2017, a 3-D elasto-plastic analysis under regional stress was carried out using a model rotating technique newly proposed. The results show that the calculated results of the elasto-plastic analysis are closer to the measurement results than those of the elastic analysis. This means that the clay-bearing rock at the foot of the rock slope has shown plastic behaviors. However, countermeasure by rock bolts and shotcrete commenced in 2018 is expected to have inhibited the plastic deformation of the rock slope because the decreasing rate in change in distance became smaller since 2018.