Introduction

As part of ensuring safe and productive operations in open pit mining, it is vital to undertake displacement measurement of rock slopes to determine their stability. At Higashi Shikagoe limestone quarry in Hokkaido, Japan, automated polar system (APS) was installed to monitor rock slope displacement. Surface displacement measurement techniques are commonly used to analyze and characterize rock slope deformation, and to detect failure mode in open pit mining operations. In this study, APS data was used to characterize rock slope deformation first by analyzing change in distance to understand overall rock slope deformation behavior, and then using resolved 3D data to obtain displacement characteristics and identify driving forces behind deformation.

The lithology of the site mainly includes limestone, schalstein and slate. Parts of the schalstein and slate zones were subjected to significant weathering and thick clay seams comprise parts of the rock slope, especially at the 420 meter level. In addition to weathering, there is extensive fracturing and the dominant geologic structure is a right lateral fault with a dip and dip direction of N70° E-80° S and N70° E-75° N respectively. Uniaxial and triaxial compression tests on intact limestone and schalstein blocks from the quarry revealed the presence of high strength rocks on site. This demonstrates the complexity of the site's geology.

The quarry is considered to be small scale in terms of production, but it has a history of about 100 years of operations. Operations are undertaken mainly between the months of April and November every year because of severe conditions in winter. Operations on site comprise excavation and backfilling.

Displacement data

Figure 1 shows change in distance over a three-year period and it indicates that over time, there is a steady decrease in distance between the rock slope and the beam generating point. The rate of change in distance is almost constant but there are periods of accelerated displacements. With a few exceptions, changes occurring during periods of accelerated displacement are not reversible.

Analysis of 3D data revealed an influence of temperature in z direction whereas x and y direction data showed acceleration during summer periods.

Effects of excavation and backfilling

A number of researchers have applied elastic analysis to investigate effects of excavation and backfilling (Obara et al. (2000), Kodama et al. (2013)). In this research elastic analysis was undertaken using finite element code to simulate deformation of three dimensional models of the quarry that represented different stages of excavation and backfilling. The models were based on site topography and it was assumed that the rock mass was homogeneous, isotropic and linearly elastic with a unit weight of 26.2kN/m³. Throughout the analysis, Young's modulus was kept at 1 GPa. Boundary conditions were set by applying zero displacement vectors on the side and basal model surfaces. To obtain the displacement field due to differences in self weight of rock, the following formula was used:

$$Ku_g = f_g$$

where $K$ is the element stiffness matrix, $u_g$ is the displacement field and $f_g$ is nodal force according to self weight given by $\rho$ (rock density) and $g$ (gravitational force).

Analytical results at Poisson's ratio value of 0.1(Figure 2) showed no good agreement with measurement data in y and z directions. From these results it was concluded that observed displacement on site was not due to excavation and backfilling.
Effect of Rainfall

Comparison of horizontal displacement and rainfall showed good agreement, especially between summer accelerations and rapid increase in cumulative rainfall (Figure 3). This shows that rainfall is one of the driving forces behind measured rock slope deformation at the site. In y direction, the right side of the slope produces the strongest response to rainfall occurrence (Figure 3 (b)), whereas the upper part (Figure 3 (c)) shows a lesser response in comparison to the lower part (Figure 3 (a)) of the slope. This indicates a possible increase in water pressure at the lower part of the slope and flow through the major discontinuity following infiltration of large amounts of rainfall.

Effect of discontinuities

Displacement vectors are shown with distribution of discontinuities in Figure 4. In 2014/15 displacement direction was mainly along the trend of the major discontinuity. In general there is a difference in point behavior depending on location relative to the fault line with points above having greater displacement magnitudes.
To confirm that there is sliding along discontinuities, the linear relationship between displacement in x direction and y direction during the high rainfall period was investigated. Considering orientation of the major fault line, the linear relationship between x and y displacement (Figure 5) when rainfall is the main driving force confirms sliding along weak planes following infiltration.

**Conclusions**

Measured displacement from Higashi Shikagoe shows a steady decrease in distance between rock slope and base point. Periodically, there are periods of accelerated displacement which are responses to precipitation events mainly rainfall. Numerical analysis results did not give good agreement with the measured displacements leading to the conclusion that observed displacements are not primarily due to excavation and backfilling. Considering orientation of the major discontinuity on site and the direction of displacement vectors, it can be concluded that the discontinuity plays a major role in rock slope deformation. This effect is exacerbated by infiltration of large rainwater amounts. Drainage of the slope along this discontinuity could be an effective means of preventing instability.

**References**

