Slope monitoring using combined optical and drone survey tools

P. Nater
Pöyry Switzerland Ltd.
Herostreet 12
8048 Zurich
Switzerland

S. Amvrazis
Pöyry Austria Ltd.
Strubergasse 30
5020 Salzburg
Austria

R. Fretz
Pöyry Switzerland Ltd.
Herostreet 12
8048 Zurich
Switzerland

V. Crisp
Pöyry Switzerland Ltd.
Herostreet 12
8048 Zurich
Switzerland

The Nam Theun 1 Hydropower Project is currently under construction in central Laos along the Nam Kading River. To create a platform for the construction of the two shaft powerhouses significant surface excavations were performed. The final steep slope with intermediate berms has a height of ca. 110 m. A monitoring program was established consisting of optical survey with fix prisms and regular drone flights for photogrammetrical evaluation. A pattern of large colour markers was installed for large area interpretation of displacements based on the concept of PIV methodology using drone photos. Due to variable illumination, dust, humidity and obstacles the application of standard PIV methods was not successful. With the introduction of AI pattern recognition techniques reliable marker recognition could be achieved while reducing the amount of manual interaction to a minimum. The originally low accuracy could be raised to a level comparable to optical survey.

1. Introduction

The Power Waterway of the Nam Theun 1 Hydropower Project is located on the left abutment and consist of a single tunnel conveying water from the reservoir to the powerhouse that is formed by two shafts where three turbines are placed (one shaft with two units, the second shaft with 1 unit). To create a reasonable platform for the construction of the two shafts significant excavation work was performed. The overall height of the so called Powerhouse slope reaches approximately 110 m. The integrity of this slope is crucial for the ongoing construction of the shafts and later for the operation of the scheme.

Initially the anticipated rock conditions were interpreted to be favourable as the reported discontinuities did not promote structural failure and the predominant cliff forming sandstones bear enough strength. Optical survey was selected as standard monitoring tool. The targets were placed along two sections covering the entire height of the slope. The interpretation of data collected with drone flights was established in parallel to the ongoing works. Colour markers were installed on the berms over the entire excavation following a pattern of approximately 5 m x 5 m. Initially all markers were considered for processing. To simplify the development process the area for interpretation was later limited. Still the resulting procedure is scalable to almost all convenient size. The focus of this paper is to present the results obtained in a limited area.

2. Design and support

The shape of the Powerhouse slope was laid out with slopes and berms where inclination, height and support pattern could be selected according to the anticipated rock type. The inclination varies from 2v:1h to 5v:1h and the height from 6 m to 15 m - the 15 m were not applied. The berm width was always kept constant with 3 m. The support consists of fully grouted steel anchors, shotcrete cover and drainage tubes. The drainage tubes are wrapped in geotextile to limit potential washout of fines.

3. Specific challenge

During excavation of the upper north part of the Powerhouse slope adverse geological conditions compared to the design assumptions were revealed. The excavated rock was partially heavily weathered and almost disintegrated resulting in soil like geomechanical properties. Due to space constraints the shaping of the slope could not be adjusted as per design where a specific layout was foreseen for slopes excavated in soil. Still bench height was reduced where possible and a tight support pattern was applied. First minor cracks on the shotcrete cover appeared already during the dry season in March 2018 together with small displacements in the order of mm. After heavy rainfall during monsoon season 2018 more cracks were observed and optical survey showed displacements in the order of several cm at specific locations. Figure 1 shows the Powerhouse slope with the location of the cracks in the shotcrete and the initial monitoring points for optical survey. Later additional monitoring points were installed to track the development of the displacements. As the times series starts after the events the information is of limited value.

Fig 1. Overview on the Powerhouse slope together with the observed cracks (red lines) and initial optical monitoring points (numbered circles).

4. Geology

At the Nam Theun 1 site the bedrock consists of a sedimentary Mesozoic series. The rocks forming this series were grouped in coarse grained layers (sandstones and conglomerates) and finer grained layers (siltstones). A dark grey mudstone is locally found at the contact between these two layers or as lenses in the coarse-grained layers. Bedding planes dip gently toward the north in the whole project area. Bedding-parallel shear zones were recognized during investigations phase and shown as red lines on the maps and profiles. Weathering is not simply decreasing with depths but develops along complex paths, with deep weathered zones found along siltstone layers and locally along sandstone layers, in association with shear zones.

In the portion of the Powerhouse slope affected by cracks the underground consist of soil and of moderately to highly weathered grey sandstone and siltstone. The conditions are revealed in the figure below.

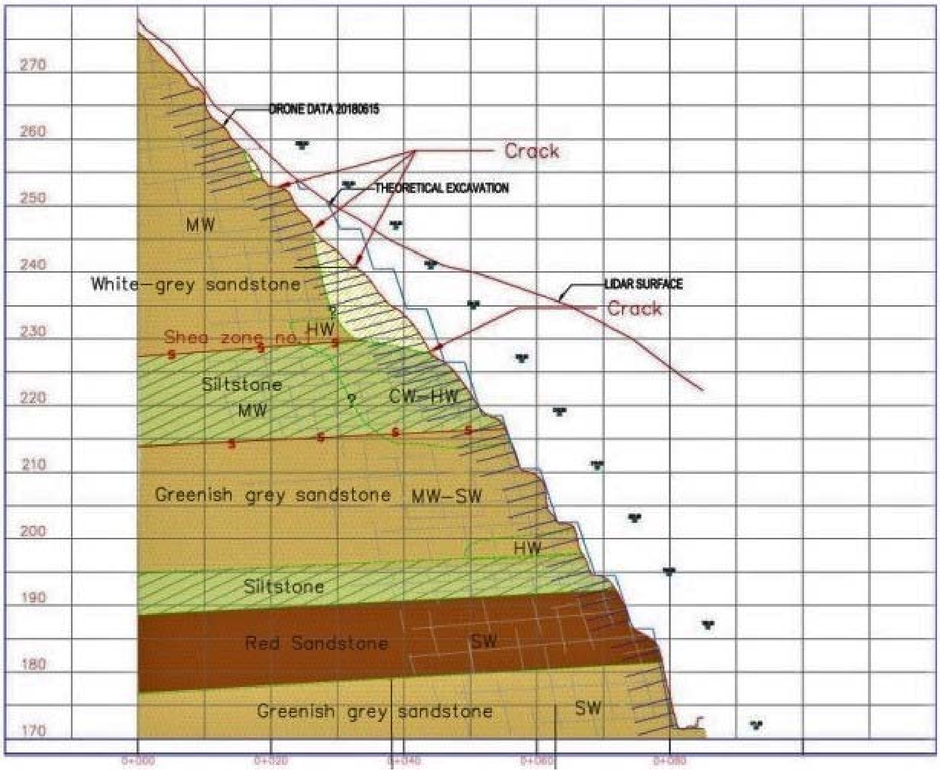

Fig. 2. As built geological section through the area of interest - sandstones brown, siltstones green, shear zones red, original ground surface red, theoretical excavation line as per design blue.

5. Slope monitoring

Optical survey was set up as standard monitoring scheme. A total station points at reflectors fixed on the shotcrete surface, the reflectors are aligned on two major sections perpendicular to the slope. A net of fixpoints outside the perimeter of the slope was established to guarantee for accurate absolute measurements. The measurements are carried out manually and reported on a regular base. As the entire construction site is surveyed by means of drone photography the use of the 3d models and orthophotos for displacement tracking was discussed. For this purpose, the application of standard PIV (Particle Image Velocimetry) methods was envisaged as this method is already widely established in geotechnical laboratory and model testing. To simplify the detection of specific features in orthophotos from consecutive flights well detectable colour targets - so called markers - were sprayed on the shotcrete surface.

All description below is based on the comparison of 2 orthophotos only. The first one was created in June 2018 (before the rainy season 2018), the second one was created in April 2019 (before the rainy season 2019). Within the area of larger displacements only two optical monitoring points were present. The total displacements vs. the observation time of these 2 points is presented in Figure 3. At point Nr. 08 after the onset of displacements no data is available for 30 days. At point Nr. 12 also the onset of displacements was not recorded.

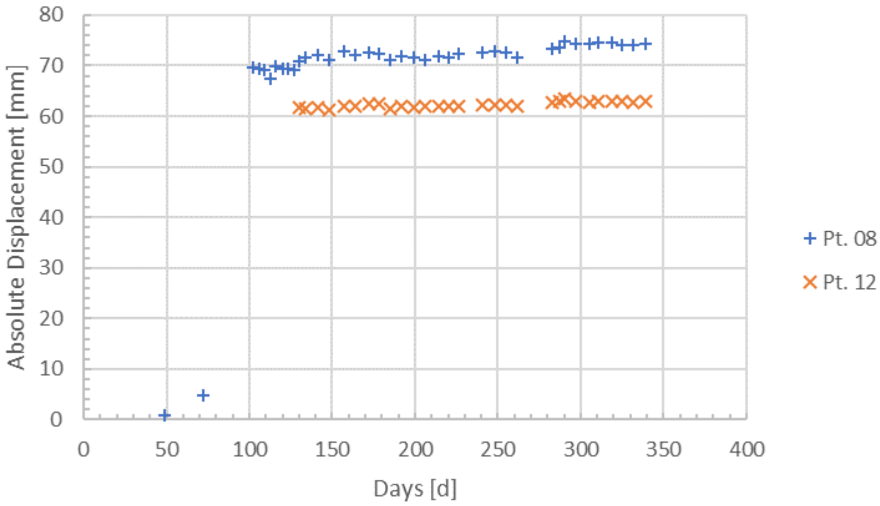

Fig. 3. Absolute displacement of monitoring points 8 and 12 versus observation time.

The area for processing was cropped down to the area of major displacement to limit the amount of data and to simplify checking procedures. Within this 50 m x 100 m = 5'000 m2 a number of 106 markers were placed. In a first series triangular black markers were used, later red circles of 30 cm diameter were installed. Considering the established flight regime for drone survey the achieved pixel resolution was 2.3 cm/pixel. For this reason, the initial target precision considering the PIV evaluation of orthophotos was optimistically expected to be within 2 pixels equivalent to 4.6 cm. It seemed obvious that only significant displacements could be detected this way even under optimal conditions. The challenges for automated image processing were the variable weather and lighting conditions together with wet areas after rainfalls, reflections debris and dust. The subsequent noise comparing the orthophotos caused significant manual and hence ineffective post processing of the photos. Also picture processing and alignment of the orthophotos initially caused small but systematic errors which theoretically could be filtered and corrected. The application of standard PIV technique for this purpose was not efficient - even though the markers seemed to be well visible.

6. Realized enhancement

The system was then enhanced by tracking colour discontinuity difference, absolute RGB and RGB gradients with computer vision technology and AI algorithms. The technique was trained the way to automatically spot 70% - 90 % of all placed markers independently of their shape and colour. The system was enabled to automatically calculate the centroids of the sprayed markers to compare only the centre points between the two consecutive drone flights. With this technique the pixel resolution of 2.3 cm/pixel was bypassed as a limiting factor in terms of precision.

Even though almost all markers were detected some of them could not be sufficiently determined for further processing. Due to the challenging site conditions these were either damaged, partially covered by dust or debris or reflections and lighting affected their appearance. To improve the number of reliably tracked markers the pattern recognition system was enhanced by a machine learning method to fill or replace the incomplete markers with a virtual equivalent and therefore to define a precise centre point again. If the procedure is consequently applied on all targets no significant error is introduced. An example of targets with overlay is presented in Figure 4. The system also detects additional non-obvious features and artefacts which are automatically excluded from later processing.

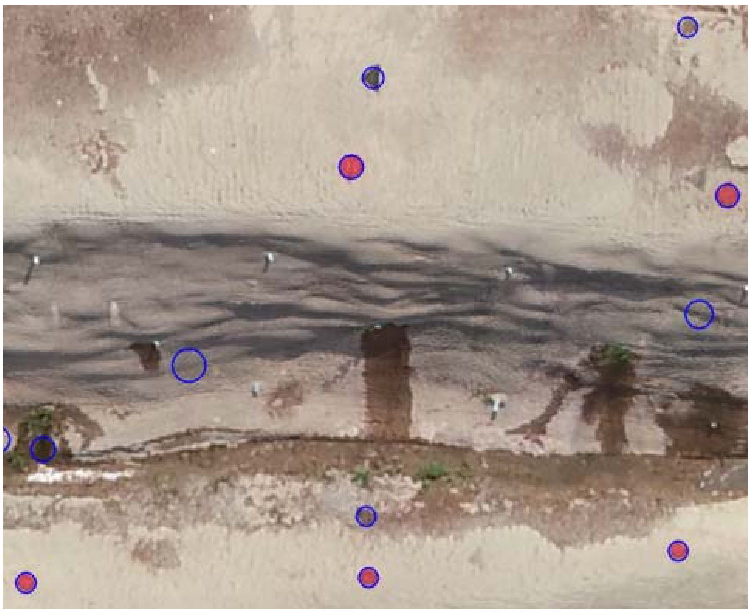

Fig. 4. Targets with a circular overlay including additional and non-obvious features.

As a final step the system finds matched markers between the images applying a nearest neighbour algorithm based on a given minimum distance. This also helps to avoid false positives. From the 106 markers placed in the test field a total of 80 markers could be tracked. 2 out of the 80 could be automatically excluded as false positives - these two were newly placed by the site staff and subsequently only appear on one of the orthophotos.

7. Results

Each centre of the markers was compared with the corresponding matched ones between the consecutive drone flights. The differential model now has a satisfactory technical precision in the range between +/- 6 mm. The results were validated by the optical survey, the existing geological model and the locations of crack appearance. The following figure illustrates the displacements on a colour overlay on the slope. According to the interpretation of the marker displacements the maximum displacements were larger than the ones recorded by optical survey. The latter are at the outer part of the affected zone.

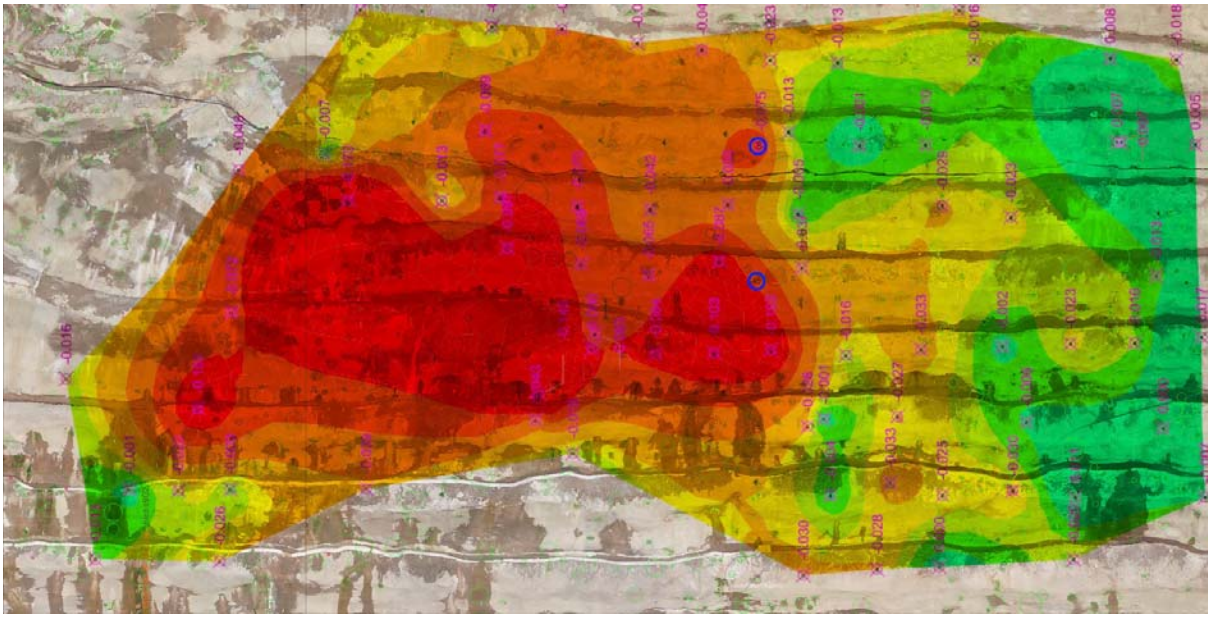

Fig. 5. Range of major interest of the Powerhouse slope together with colour overlay of the absolute horizontal displacements. The blue circles represent the location of the optical survey points Nr. 08 - upper one - and Nr. 12 - lower one.

A similar result with even higher precision could theoretically be achieved by installing additional optical survey points over the entire slope. The placement of 80 resp. 78 optical targets and their frequent measurement in this area seems not applicable.

8. Interpretation

The displacement distribution is now available over a significant area and not only at specific points. The area with high displacement correlates well with the revealed rock mass conditions, in this case the highly weathered or even disintegrated rock. Most likely due to the relative stiffness and/or brittleness of the shotcrete cover the perimeter of cracks extends beyond this area. Further improvement of the support measures can now be optimized for the specific conditions.

9. Conclusions

Automated pattern recognition techniques allow for gathering displacement information over large areas with reasonable precision. Even by applying dense marker patterns the amount of data is small and suitable for being processed by means of relatively light algorithms within short time. The spatial distribution supports the detection of specific areas of interest and facilitates the efficient application of additional measures. High precision optical monitoring cannot be replaced as it is used in the minimum as a benchmark.

In case long-term durability is required marker preparation and maintenance needs to be specifically investigated. The applied technique helps to overcome a major part of the issues caused by insufficient target visibility. Still maintenance needs to be planned; e.g. by replacing entire markers or completing markers with flaws. There it needs to be ensured that the technical precision is not challenged by manually created errors; e.g. the imprecise replacement of markers.

The pattern recognition method and the corresponding algorithms were introduced at the WTC2019 (Amvrazis et al. 2019) after the successful implementation as a pilot project at Brenner Base tunnel in Austria (Voit et al. 2017). There the so-called AI system was developed by Amvrazis to map the geologic structures and use the information to predict overbreaks progressively for each drill and blast procedure (patented by Amvrazis).

Acknowledgments

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The Authors

P. Nater has graduated at ETH Zurich, Switzerland, and obtained his PhD at the same institution. He works for Pöyry since 2008 and his involvement as Senior Geotechnical Engineer comprises all design and execution phase of hydropower and underground projects. The focus is on the geo-mechanical behaviour of soil and rock together with the corresponding measurement, modelling and monitoring techniques.

S. Amvrazis has graduated from National Technical University of Athens where he obtained his diploma and PhD in survey engineering and applied mathematics. He works in Pöyry since 2018 and came with background in developing machine learning and deep learning applications combined with computer vision and pattern recognition. He works as Principal Engineer and Innovation Manager of digital solutions and holds 3 patents dealing with autonomous geologic inspection and tunnel excavation predictions.

R. Fretz has graduated at Engineering College Basel, Switzerland, and obtained a B.Sc. Diploma in Surveying. He works for Pöyry since 1999 as a Surveying Engineer and Section Head of a Surveying Team and was involved in many major civil construction projects.

V. Crisp has graduated in Survey Engineering in 2008 from the University of Muttenz, Switzerland. She is engaged as Survey Resident Engineer for the Nam Theun 1 HPP since 2017. She carries out all the measurements by optical survey methods or by drone.