Deepening an old, verticalized pit: rock slope instability hazard assessment using a "digitally augmented" structural database (Flône limestone quarry, Belgium).

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Abstract:

We present the methodology and results used to assess the rock slope instability hazard of the Flône pit (Belgium) by means of a deterministic kinematic stability analysis. This study's particularity resides in the "digital augmentation" of the field mapping structural database (by a factor 5), based on semi-automatic point cloud analysis. Our data show that the main instability hazard is flexural toppling on the northern and southern fronts of the actual pit. Wedge sliding constitutes a moderate hazard on the western and eastern fronts. Planar sliding, although minor in the current situation, will constitute a significant hazard for interbench rupture during future excavation, due to the presence of an anticline structure at depth inferred from 2D interpreted geological cross-sections. Our georeferenced, augmented structural database has enabled to generate a synthetic rock slope instability hazard map that constitutes the basis for recommending targeted monitoring solutions during future excavation works.

Key Words: Point clouds, Drones, Laser scanning, 3D, Pit stability Monitoring

Profundización de un antiguo pozo verticalizado: peligro de inestabilidad de roca utilizando una base de datos estructural "aumentada digitalmente" (cantera de caliza de Flône, Belgica)

Presentamos la metodología y los resultados utilizados para evaluar el peligro de inestabilidad de la roca del pozo Flône (Bélgica) mediante un análisis determinista de estabilidad cinemática. La particularidad de este estudio reside en el "aumento digital" de la base de datos estructural de mapeo de campo (por un factor 5), basado en el análisis semiautomático de nubes de puntos. Nuestra data muestra que el principal peligro de inestabilidad es la caída de la flexión en los frentes norte y sur del pozo real. El deslizamiento de cuña constituye un peligro moderado en los frentes occidental y oriental. El deslizamiento plano, aunque menor en la situación actual, constituirá un peligro significativo para la ruptura entre bancos durante la excavación futura, debido a la presencia de una estructura anticlinal en profundidad inferida de las secciones transversales geológicas interpretadas en 2D. Nuestra base de datos estructural aumentada georreferenciada ha permitido generar un mapa sintético de peligro de inestabilidad de la pendiente de roca que constituye la base para recomendar soluciones de monitoreo específicas durante futuros trabajos de excavación.

1. Introduction

With increasing environmental awareness, optimizing available resources is key to ensure future sustainable extraction activities. Nonetheless, optimizing resources by deepening a pit and verticalizing its fronts may go along with increased instability hazard. Lhoist Group plans to further exploit the limestone resource of its Hermalle quarry —a 2.5 km long for only 300 m large elongated pit bordering the Meuse river in Belgium (Figure 1) — by deepening its westernmost part (the "Flône" pit). The pit had not been exploited since 2007, and since then the 3 upper benches are set in their "final" position (i.e. 20 m vertical each, with 5 m interbench distance). Although no major instability hazard has occurred since this time, it was imperative for security reasons to (i) assess the instability hazard in such narrow and steep conditions, and (ii) have a view on the resource at depth, prior to restarting extraction activities in the Flône pit.

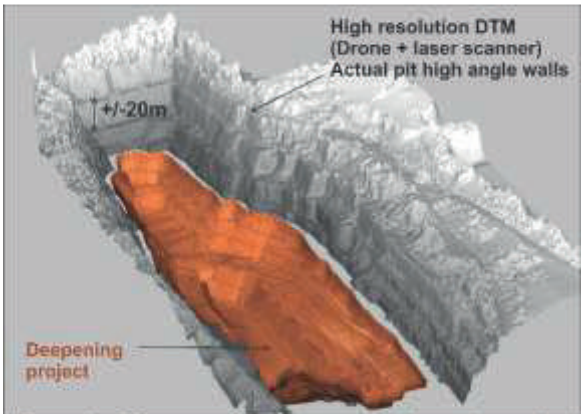

Figure 1 : Flône actual pit geometry & deepening project

2. Geological context

The Hermalle quarry exploits visean limestones and dolomites near the contact with a major tectonic suture, the Midi Eifel thrust zone. The sedimentary succession in the quarry is thus strongly deformed, in general either steeply S-dipping with normal polarity, or steeply N-dipping with reverse polarity in the south and the north of the pit, respectively. The northern front also shows a tight, upright fold, with an axial surface dipping towards the pit.

3. Methodology

3.1 Digitally augmented structural database

The high-density point cloud has been constructed by merging a fix station laser scanning acquisition from the base of the pit, with an aerial (drone) photogrammetric survey. This dual acquisition has allowed us to increase and homogenize point density, especially in scanning dead angles for geological and geotechnical study purposes.

Our structural database based on (i) field mapping (157 DGPS stations, 211 planes – S0, S1, fractures, faults– and 24 lines – slickensides, fold axes) and (ii) Lhoist archives integration (pit photographs, own structural database) has been digitally augmented by semi-automatic, point-cloud based picking of ~1000 plane orientations using *CloudCompare* software (Figure 2).

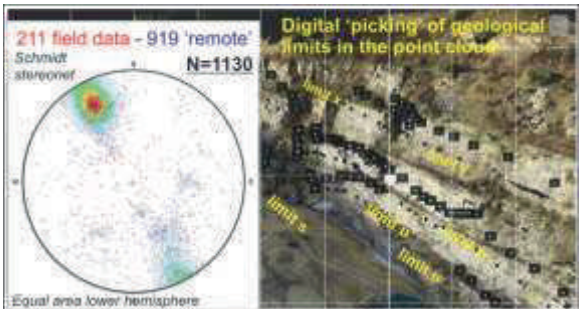

Figure 2 : 3D point cloud geological limits picking and results of field & remote structural data base

The georeferenced point cloud not only allows to retrieve data from inaccessible areas such as of each of the three 20 m high, verticalized fronts of the Flône pit, but also enables to refine the geological model and perform targeted detailed kinematic slope stability analyses precisely locating the subsets of problematic structures directly in GIS. Remote data measurement is reliable, efficient and a powerful methodology for both geological and geotechnical studies.

3.2 Interpretive geological cross-sections

In order to evaluate simultaneously the evolution of the limestone resource at depth and the instability hazard during excavation of the future pit, 4 interpretative cross-sections have been produced. These allowed discussing the instability hazard in function of the structural uncertainties still remaining at depth and making recommendations for monitoring and additional investigations, as well as general recommendations regarding future pit design and excavation.

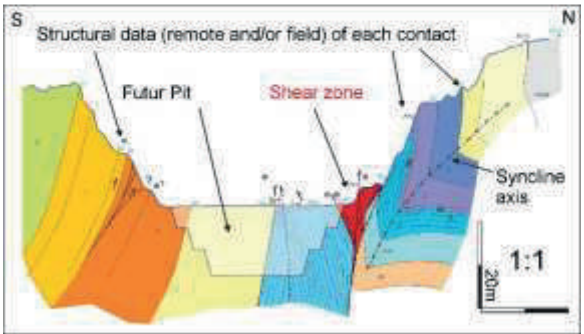

Figure 3 : structural cross section enhanced by remote structural data

3.2 Rock slope kinematic stability analysis

Three rock slope instability hazards have been investigated (planar sliding, wedge sliding and flexural toppling) by means of rock kinematic stability analysis using *Rocscience* software suite. Investigation of general failure mode was not part of this study, considering the overall strong character of the exploited limestones and dolomites.

For each front (South, North, West and East) we have computed plane, wedge and flexural toppling kinematic stability analysis based on >1000 planes covering the 4 mapped tectonic units. To perform the kinematic stability analyses based on the Markland's test (Hoek and Brey, 1981), we have considered an average slope dip of the quarry fronts of 75°, a friction angle of 30°, 222 augmented, georeferenced structural database, we have then been able to produce detailed instability hazard maps.

4. Results

4.1 Geological – Structural mapping and cross-sections

Our new data have highlighted a more complex structure than was previously known in the Flône pit, in particular the yet unknown presence of high angle thrusts and backthrusts crosscutting the $S_{0/1}$, and recumbent folds and intense shearing affecting the western- and easternmost part of the pit. We have defined 4 tectonic units in the Flône pit, each characterized by a different degree of deformation: UT-1 is composed by dominant $S_{0/1}$ planes, UT-2 is in addition crosscut by 1 family of high angle (back-) thrust faults, UT-3 shows complex (recumbent) fold geometries and is cut by 2 or more fracture/fault orientations, and UT-4 corresponds to decameter scale, steeply dipping deformation zones (e.g. inverted flower structures) where $S_{0/1}$ is no longer visible.

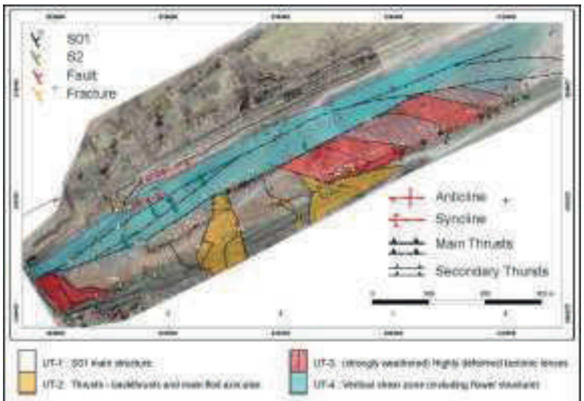

Figure 4 : Structural map and Tectonic Units 1 to 4

4.2 Instability hazard assessment

Rock kinematic stability analysis (deterministic approach) based on a near comprehensive georeferenced structural database – Figure 5- has shown that the main rock instability hazard in the Flône pit concerns flexural toppling on the North and

South fronts (46 and 47% respectively). The East and West fronts, which are dominated by UT-2 and UT-3, only show moderate wedge failure hazard (11%), mainly where $S_{0/1}$ intersects (back-) thrusts.

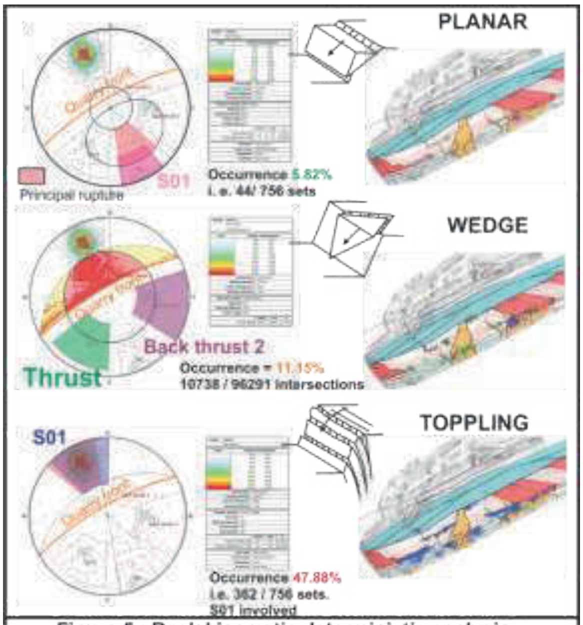

Figure 5 : Rock kinematic deterministic analysis-Results and GIS localisation of the involved planes

Planar sliding hazard is generally low (2 to 10%) on all fronts, but our interpretative cross-sections have highlighted that this hazard may significantly increase during future excavations – Figure 6. In particular on the northern front, where some uncertainties remaining on the geometry of an anticline at depth, when deepening the pit, generate significant inter-bench rupture hazard (see example cross-section).

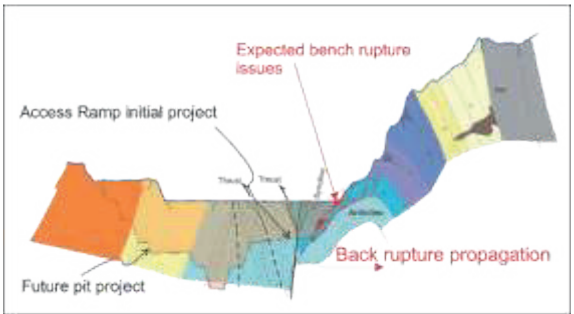

Figure 6 : Planar sliding along the anticline flanc

5. Discussion

Point cloud based structural data acquisition has enabled augmenting (x5) our field mapping database in the Flône quarry to assess geological model and support rock instability hazard (planar and wedge sliding, flexural toppling) with a high degree of confidence. However, this very powerful geometric approach should always complement – but not replace – the geological/geotechnical field expertise, as instability hazard not only relies on geometric parameters. Our combined geological and geotechnical surface analysis has enabled anticipating future hazard defining a targeted monitoring program depending on the locations of the instability hazards identified across the pit.

6. Conclusion

Digitally augmented structural databases based on georeferenced point cloud analyses now enable performing deterministic rock kinematic stability analysis at the scale of a pit with a high degree of confidence due to the enormous amount of robust structural data that can be gathered in an efficient way, but field geological mapping and rock mass characterization should prevail to make a consistent stability assessment.

7. References

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