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Geotechnical risk assessment of an underground magnesite mine

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An inter-disciplinary geotechnical study has been carried out in an Austrian magnesite mine. The paper describes the how geological data, *in situ* and laboratory tests as well as subjective, empirical, geophysical and numerical methods have been used to identify critical areas in the mine.

In einem österreichischen Magnesit Bergbau wurde in den letzten Jahren eine interdisziplinäre geotechnische Studie durchgeführt. Der Vortrag beschreibt den Einsatz subjektiver, empirischer, geophysikalischer und numerischer Methoden zur Identifikation geotechnischer Problembereiche

Ces dernières années des études géotechniques interdisciplinaires sont effectuées dans une mine souterraine de magnésite en Autriche. Ce rapport trace l'application des méthodes subjectives, empiriques, géophysiques et numériques pour identifier les zones problématiques dans la mine

Introduction

The need for a methodology of geotechnical risk assessment of Austrian underground mines was formulated by the Austrian mining Inspectorate. The Veitsch Radex GmbH & Co as owner of one of the largest Austrian underground operations participated in the development of this procedure. The geotechnical investigations started in 2000.

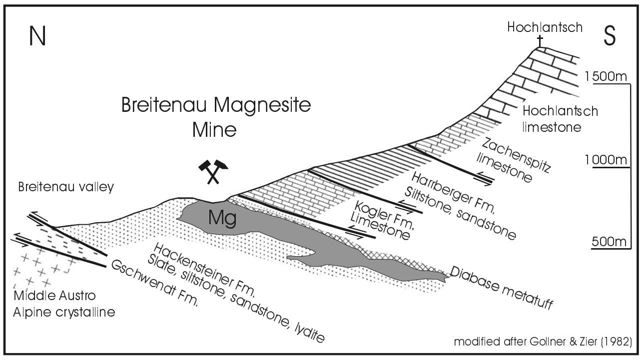

Figure 1: Geological cross-section through the deposit

General description of the investigated mine

The study mine is located in the eastern part of the Austrian Alps 150 km SW of Vienna. The sparry magnesite deposit is located in the Hackensteiner Formation of the Silurian/Devonian Laufnitzdorf Group which is a part of the Graz Paleozoic Thrust system (Fig. 1). The massive mineral body has a length of approximately 2 km, and a width of 150 m to 500 m. The thickness varies between 50m and 200 m. The general angle of dip of the deposit is ~ 25° to the south and opposite to that of the mountain slope. The overburden varies between 0 m up to 1,000 m. The tectonic regime is dominated by two steep fault systems trending in ENE-WSW, and NNE-SSE directions. These systems displaced parts of the mineral body for distances of a few meters only. Host rocks of the magnesite are anchimetamorphic slates rich in organic material, siltstones, sandstones, lydites, limestones and metatuffs of poor to very poor mechanical properties. Mining activities started at the beginning of the last century, and a remaining lifetime of 20-30 years is estimated. The mining method is post pillar mining using uncemented backfill. The pillars are rectangular in cross-section with a width of ~5 m and a length of ~15 m. In a first step a 7 m high opening at the deepest point of a mining area is excavated. Afterwards backfill is placed to a height of 3.5 m. The backfill is used as a working level for the next 3.5 m mining slice. Depending on the geometry of the deposit up to 26 slices have been mined resulting in pillar heights ranging from 7m to more than 90 m.

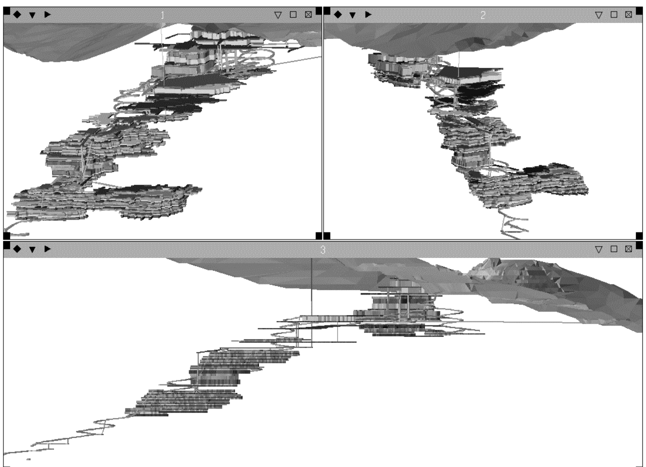

Figure 2: 3D view of the existing mine

Geological investigation

In the first step a full 3D computer model of all excavations was created, Figure 2. All available geological information, drill core data, geometry of the deposit, geostatistical block model etc. were added to this model. Afterwards a detailed geological mapping of the whole mine was done. The aim was the identification of geotechnically homogeneous blocks. The lithology and water inflow was documented for this purpose. On all accessible rock walls of the mine the spacing of fractures was determined on a line 1.5 m above of the floor level. According to the different intensity of tectonic overprinting the rock wall conditions were divided into four classes with average spacing of >200 mm (class 1), 200/50 mm (2), 50/10 mm (3), and 10/0 mm (4). The total investigated wall length which was rated exceeded 20 km. Areas of class 4, and parts of class 3 were situated within shear zones. In addition to fracture densities some 3000 dip and dip direction measurements of fractures and major faults were taken.

Based on a 3D digital computer model, where all these data were implemented, it was possible to divide the deposit into nine irregularly shaped blocks of homogeneous geotechnical properties. All blocks are separated by major fault zones, Figure 3. Two block types were found, namely massive/compact blocks of >150 mm average joint spacings and relatively weak, highly fractured, and sheared rock formations with average joint spacing of <20 mm. Redolomitisation of the magnesite along the joints and faults, and growth of secondary gypsum crystals in the fractures was widespread. Because of the differences in the geological structure differences in the geotechnical behaviour can be expected in this two rock types. This was confirmed by underground observation.

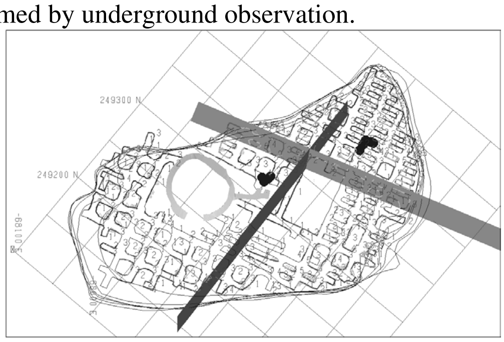

Figure 3: Mining area with regional joint system

Geotechnical investigation

In addition to the fracture density mapping a subjective rating of all excessible rock wall conditions of the drifts and pillars was performed in four steps as follows:

- Subjective rating based on 5 classes of general rock wall condition according to size of wedges and slabs (i.e. notch depth, class 1: <0.5 m, 2: 0.5/1 m, 3: 1/3 m, 4 and 5: >3 m), filling, spacing, and dimension of mining induced and natural joints, faults, relation of joints and faults to each other and to the geometry of the walls, presence of water, thickness and height of pillar, and others.

- Shape of side wall (Figure 4).

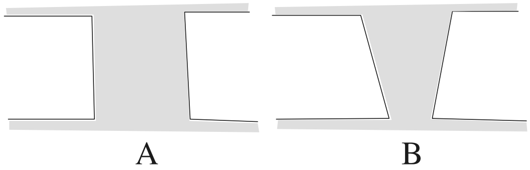

Figure 4: Classification according to shape of side wall. A: vertical, B: thickness deminishing from top to bottom.

- Rock wall conditions of drifts and pillars according to tectonic situation (Figure 5).

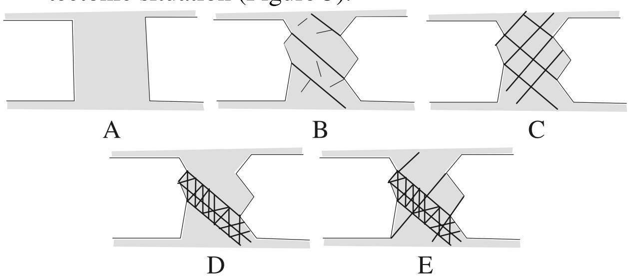

Figure 5: Classification of side walls in respect of fractures and faults. A: homogeneous, B: one premium joint set, C: several major joint sets, D: one major shear zone, E: combination of joint set plus shear zone.

- Wedge, slab breakoff behaviour (Figure 6).

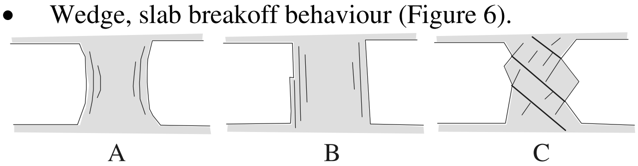

Figure 6: Classification according to induced stress. A: curved rock slabs, B: plane rock slabs, C: wedges controlled by natural fractures.

These subjective data were implemented in the 3D model of the mine.

A detailed geotechnical investigation was done to determine the geomechanical properties of the two types rock mass. For this purpose the parameters commonly used in rock mass classification systems like Barton's Q [1] [2], Bieniawski's RMR [3] [4] [5], Laubscher's MRMR [10] or Hoek & Brown's GSI [7] [8] were evaluated on site. This general assessment was completed by measurements of more than 1,300 p-wave velocities on 150 geophysical sections through the pillars. In addition to the p-wave measurement twenty eight drill cores were extracted from the pillars. The drill holes were scanned with a bore hole camera for detection of existing cracks and joint sets. Several hundred point load tests and numerous uniaxial and triaxial compressive strength tests were performed. The dynamic and static moduli of elasticity were determined.

Table 1 gives an overview of the mean values for the two geotechnical homogeneous areas according to the classification methods used. It can be seen that the compact rock mass has a much higher rating than the sheared area.

Table 1: Classification of the rock mass

Rock type	Classification system			
	RMR_{Bien}	RMR_{Laub}	Q-Barton	GSI
Sheared	30	39	0.06	25
Compact	56	56	3	62

It should be noted that the strength values of the intact rock samples from all areas were nearly identical.

In a next step the geotechnical parameters of the rock mass have been estimated using the different empirical approaches. The deformation modulus derived from different empirical relationships [2] [5] [8] [12] [15] published in recent years yielded the same result. The determination of the cohesion, the friction angle and the tensile strength was based on Hoek's equations published in 2002 [8]. Table 2 gives a summary of the estimated rock mass parameters. These parameters were used to calculate the pillar strength σ_p using the numerical code Flac^{3D}. The numerical results were confirmed by observations in the mine.

Table 2: Parameter of the rock mass

Rock type	Classification system				
	E_{stat} [GPa]	C [Mpa]	ϕ [°]	σ_t [MPa]	σ_p [MPa]
Sheared	6	3	24	-0.01	20
Compact	12	6.5	30	-0.3	29

E_{sta} static deformation modulus
c cohesion
ϕ friction angle
σ_t tensile strength
σ_p pillar strength

In addition the strength of the pillars was calculated using different empirical pillar strength equations for hard rock pillars, [5] [6] [9] [10] [11] [13] [14] [16] [18] [20]. This was not very successful. The results for the same pillar geometry varied between 20 and 80 MPa. More details of the used methodology are given by Siefert and Wagner [17].

Results of the investigations

In a first step all available information was implemented in the 3D model. The ranking of the rock wall conditions highlighted some areas with actual geotechnical problems. A comparison of this data with the geological and structural data sets showed whether the observed problem was caused by geological zones of weakness or by mining induced stress. The clarification of the cause of the problems was essential for deciding what measures should be taken by the mine to deal with the problem.

An typical example is schematically shown in Figure 7. The regular mining activities create a remnant situation for the pillar in which the main ramp is located. After starting extraction in the middle of remnant pillar major geotechnical problems were observed in the roadway. The geotechnical 3D model documented that the hole ramp is located in compact magnesite. So the geotechnical problems in this area are a result of the mining activities and not caused by geological weaknesses. As a result of this any mining activity in ramp pillars was halted and a procedure defined how to identify problems of this kind at an early stage.

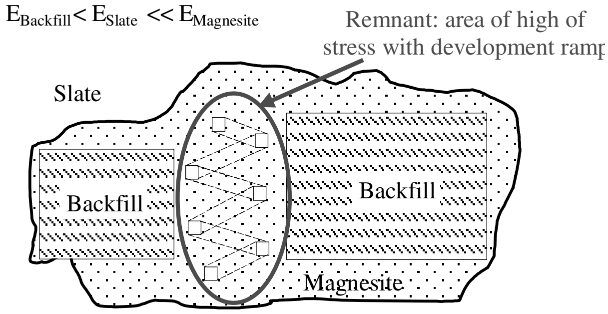

Figure 7: Cross section through a barrier pillar situation

Another example is given in Figure 8 which shows the development of a remnant situation caused by the lower mining area approaching an old mined out area. This results in a situation of unfavourable stress conditions with negative effects on the pillars. In addition the regular production blasts were also found to have a negative influence on the pillars. A visual examination of pillars over a period of three years showed a clear deterioration. This observation was confirmed by measurements of the p-wave velocity of the mine pillars. Based on this observations the mine management decided to intrduce a monitoring program in the old mining area (displacement measurements and visual observations on a regular base). Additionally it was decided to backfill most of the openings in this area during the next year.

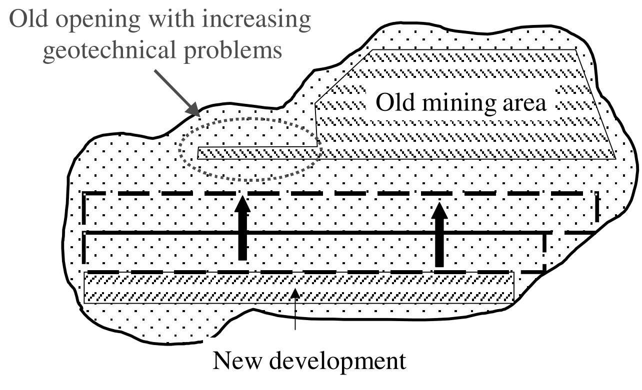

Figure 8: Cross section through a crown pillar situation

The geotechnical parameters of the rock mass were used for the re-dimensioning the pillars in deeper part of the deposit. The possibility of alternative mining methods for the deeper parts are being investigated taking into account the geotechnical conditions.

An additional benefit of the risk assessment was that the detailed geological information and the improved understanding of the geological structure of the mine provided valuable inputs for a new exploration drilling program. Some correlation's between tectonized zones and geochemistry were found. This will be used to improve the geochemical block model.

Conclusion

The study showed that the definition of geotechnical homogeneous areas is an important base for any geotechnical risk assessment.

Besides the lithology, the most useful parameters for outlining geotechnical homogenous blocks are the joint spacing and detailed information about major fault zones.

These data were combined with conventional rock mass classification systems and standard laboratory tests. Based on this a geotechnical model of the deposit as well as of the surrounding rock was set up.

The quantification of the rock mass parameters was done using empirical approaches by several authors. These parameters were used in a numerical simulation for the estimation of the pillar strength. Based on the correlation of the numerical results with the observations in the mine the input parameters were calibrated. In future these parameters can be used for the design of the new mining areas.

It should be pointed out that a full 3D model is a prerequisite for the risk assessment of an underground mine of such a complex geometry. Geological, geotechnical and geometric information is essential for the identification of areas with potential geotechnical risks and decisions concerning appropriate countermeasures.

The information and processing procedure described in this paper assisted greatly in gaining a better understanding of the geotechnical problems in the mine. This knowledge is now incorporated into the mine planing process and contributes forwards improving the safety of the mine

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