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Rodoretto talc mine (To, Italy): studies for the optimization of the cemented backfilling

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Abstract: The underground talc mine of Fontane (Prali, near Torino, North West of Italy) has been exploited for decades by conventional cut and fill method using loose fill and, in the last 30 years, using cemented backfill and exploiting the orebody downwards. With this exploitation approach, the orebody recovery and the safety of the mining operations have been greatly improved. In the new mine section, located in Rodoretto, a detailed numerical modelling has been carried out to simulate the various geometrical and mining conditions and the fill properties. In the meantime an experimental research carried out to check the possibility of using the waste rock for the fill mix have been carried out in order to establish a procedure able to reduce the filling costs.

Key words: mining, stability, backfill, numerical modelling, rock mechanics

Introduction

The underground talc mine in Fontane (Prali, near Torino, North West of Italy) has been exploited for decades by conventional cut and fill method using loose fill and, in the last 30 years, using cemented backfill and exploiting the orebody downwards (Del Greco & Pelizza, 1984; Del Greco et al., 1976, 1989; Pelizza et al., 1990). With this exploitation method the orebody recovery and the safety of the mining operations have been improved. The Rodoretto section of Fontane mine is the only one that is at present active in the area and in the Southern zone it is made of a talc mass which is located at a depth of about 400 m. The orebody is exploited on subhorizontal levels about 4 m high mowing downwards and each level is mined with the excavation of sub-parallel drifts (ranging from 3.5×3.5 m to 4×4 m) excavated from the footwall to the hanging wall of the orebody, and only backfilled with cemented fill before the lower slice is started to be exploited (Figure 1). The

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Figure 1. View of a drift supported by timber sets and hydraulic (arrows) and mechanical props

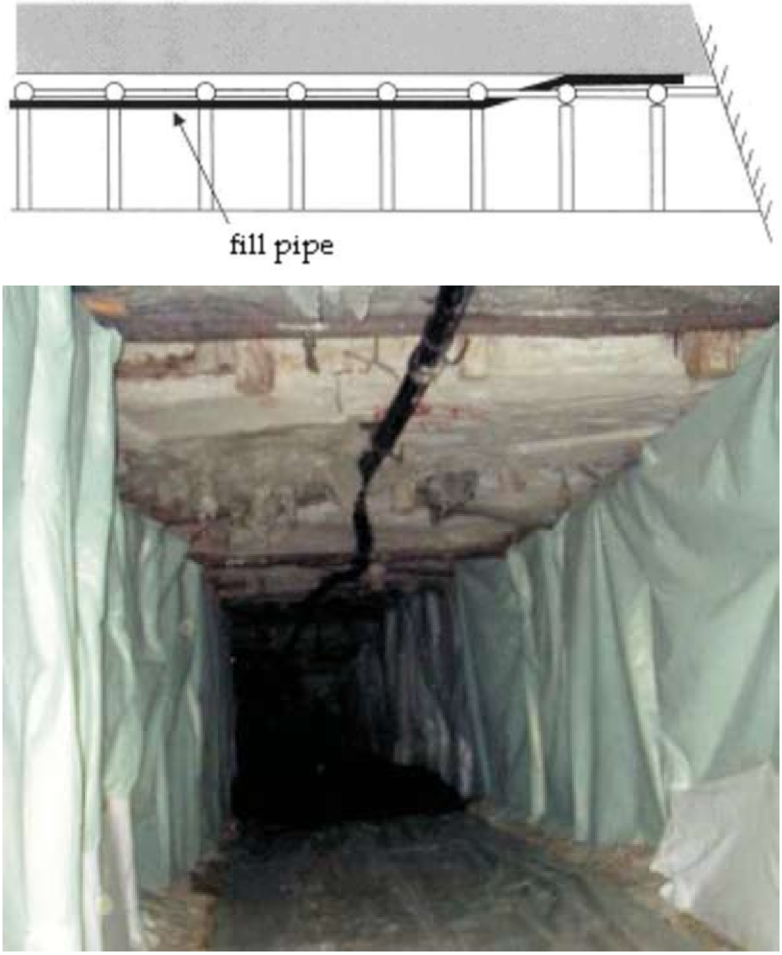

Figure 2. Scheme of the filling of a drift and photograph of a drift ready to be filled, where an impervious membrane has been installed to protect the not yet mined talc against pollution

used cemented fill is a concrete with a low compressive strength, but high workability. Due to the orebody geometry and the rock mass properties it is necessary that the cemented fill has mechanical properties that are able to control the deformation of the talc and of the embedding rock and to guarantee that the drift roof is stable in order to reduce the supports and to enlarge to the drift size, thus reducing the excavation costs and improving the profitability of the mining activity. The backfill is put in place through a HDPE pipe installed on the top of the drift using a standard concrete pump and it is carried by a mixer or from a centralized pumping station, with a pipe line that reaches the drifts of each level through the ramp and some especially excavated shafts (Figure 2).

In order to achieve these goals, the stresses induced in the embedding rock masses, in the talc and in the cemented fill, while the exploitation proceeds, were studied through numerical modelling. The possibility of using the mine waste rock as cemented fill aggregates was also examined through laboratory tests.

During excavation, the drifts are supported with timber sets (Figure 1) when there are relevant loads (for example in the first level or when the excavation in the drift is out of the backfilled area due to the orebody geometry) or with mechanical or hydraulic props when the roof is more stable, that is, below the cemented fill.

A correct study for the optimization of the fill properties must take into account both the global stability of the whole mine panel and the stability of the drift roof when the excavation is carried out in the lower level and this was carried out with a numerical model that is able to simulate the development of the exploitation of the whole mine.

GEOLOGICAL ENVIRONMENT

The geological environment of the Germanasca Valley records the complex structural history of a portion of the paleo-european continental margin, composed of a metamorphic Paleozoic basement covered by both continental and shallow water marine deposits. The Alpine orogenesis disrupted and relocated the original environments by creating a complex nappe structure with a wide variety of structural and petrological features.

The Germanasca Valley extends for an important part of its length along the contact between the Ophiolitic oceanic complex, better known as “Calcescisti (or Piemontese) nappe” and the continental domain known as “Dora Maira massif”.

Most of the existing and exhausted talc mines are distributed along this tectonic contact, hosted in the silicatic metamorphic rocks belonging to the upper part of the Dora Maira massif. According to the traditional geological approach, the geologic framework can be subdivided into two main units, from East to West:

- Brianzonese Unit (Permo-Carboniferous) composed of two distinct complexes:
    - Faetto and Pinerolo Complex: fine gneisses and micaschistes of detritic

  sedimentary origin frequently graphite rich, with quartzite and metabasites inter-layers;
  - Freidour Complex: augen-gneiss, probably representing the bedrock of the previous complex, outcropping inside the former as folded layers.
- Piemontese Unit (Mesozoic) also composed of two distinct complexes:
  - Dora-Maira Unit: garnet-chloritoid micaschistes, with gneiss, white banded marble and metabasites;
  - Calceschists and ophiolite nappe: calceschists with interlayred marble and metabasites (ophiolites).

All the previously mentioned units are visible along the Germanasca Valley, from the junction with the Chisone Valley going back up to higher elevations. The mine sites are hosted in the garnet micaschistes of the Dora-Maira unit. Several mines were exploited in the past and just one, the Fontana mine in the Rodoretto section is still active. As a general features, the white talcschist which constitutes the most part of the orebodies, shows an evident field association with the banded marble and the gneisses. The structural history and the origin of the talc is still a matter of debate and would seem to extend back in time even before the alpine orogenesis. The recent metamorphism, ductile folding and shear events associated with the formation of the Alps have overprinted the older phases and are responsible for the present structural environment where the talc can be found. The different mine (and orebody) geometries show that the economic resource concentrations are closely linked to the folding phases which created the conditions for the talc redistribution in the space and its accumulation in defined masses. In the past, thin layers were also exploited and the mining records show that panels of a thickness of less than one meter were extensively mined but recently most of the exploitation was progressively been relocated to the thicker masses, for economic and productive reasons, as is the case of the Rodoretto section.

NUMERICAL MODELLING AND GEOMECHANICAL CHARACTERIZATION

Introduction

Starting from the study of the geomechanical properties of the rock mass (talc and embedding rock) many different numerical models were developed with the finite difference code FLAC^{2D} (ver. 4.0, Itasca). The numerical models were set up with the purpose of simulating the exploitation of the whole panel made of seven levels in the south-Rodoretto mine (Figure 3). The influence of various fill conditions: mechanical properties and complete or incomplete backfilling of the drifts and of different natural stress conditions were also investigated.

Modelling strategy and input data

The adopted modelling sequence (DEL GRECO et al., 1990; PEILA et al., 1994; PELIZZA et al., 2000) consists of the following steps:

[1] excavation of the ramp tunnels;

[2] exploitation of the first level by modelling the excavation of the various drifts (which cross the model in a transversal direction), the supporting of the drifts with timber sets, and backfilling after the excavation of the adjacent drift;

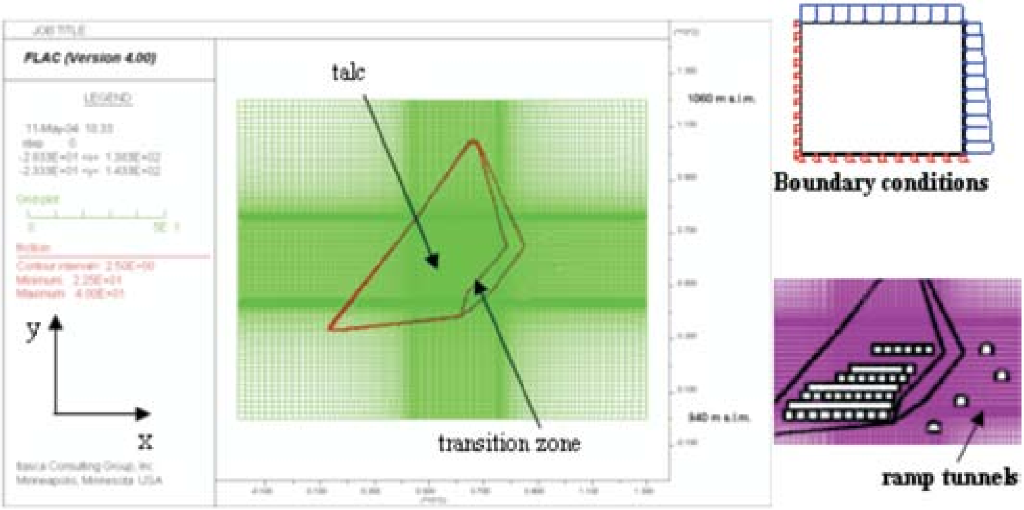

Figure 3. Global view of the geometry of the Rodoretto orebody and the numerical model (the red lines indicate the boundary of the various materials) the applied forces and the exploited levels. The transition zone represent a weak geomechanical section which consists of chaotic rock mass with talc veins, gneiss and marble. The model is 150 m wide and 120 m high.

[3] exploitation of the second level by modelling the excavation of the drift which crosses the model in a longitudinal direction, the supporting of the drift with timber sets and backfilling at the end of the excavation;

[4] repetition of points [2] and [3] till the end of the exploitation of the 7th level.

The research was developed in three different steps:

[1] development of a set of preliminary models which were set up to define the minimum acceptable strength of the fill, taking into account the complete backfilling of the drifts;

[2] development of more refined models which were set up to study the mine condition when the drifts are not completely backfilled, as frequently occurs in the mine, but taking into account the fill strength defined in the first set of models. A value of 20 % of contact zones was considered;

[3] an analytical analysis of the stability of the drift roof, taking into account the loads which were computed in the numerical modeling and using simplified analytical approaches such as a cantilever beam or the arch model (Obert & Duvall, 1967) to verify whether the stability of the fill is ensured by the strength of the fill. In order to simulate the drift excavation advancement, an internal fictitious pressure was applied to the excavation boundary nodes and this pressure was reduced to 70 % before the supports were installed (Oreste, 1999) and reduced to zero to simulate the final excavation of the drift. Another relevant problem for a correct modelling was the definition

of the natural state of stress in the orebody, due to the geometrical and geomechanical complexity of the talc orebody and of the embedding rock and to the absence of measured data. For this reason, in the first step of numerical modeling, k_0 (the ratio between the vertical and horizontal natural state of stress) was assumed to be equal 1, while in the second step of the modelling, the stress redistribution due to the difference in deformability between the talc and the embedding rock was taken into account, as suggested by Jeremic (1987) and by Amadei & Stephansson (1997). This computation made it possible to see that an important arch effect had developed in the embedding rock (more rigid) and a reduction in the stresses in the talc was observed (Figure 3).

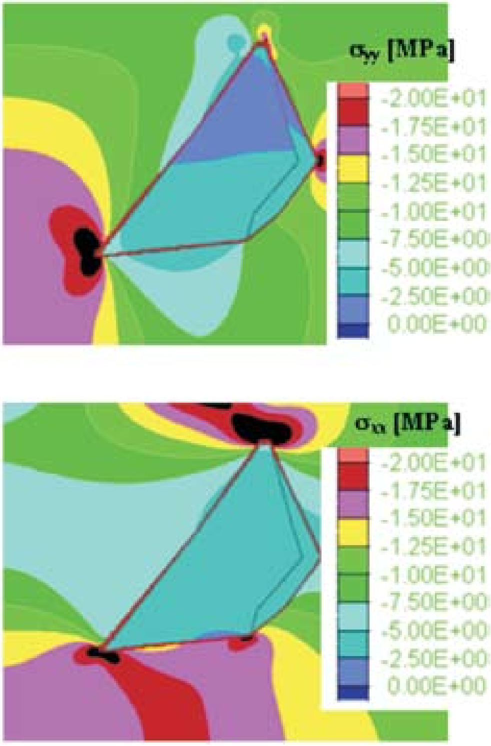

Figure 4. Computed undisturbed stresses taking into account the deformability of the talc and of the embedding rock

Geomechanical characterization

The geomechanical properties assumed in the model (Table 1) were evaluated through a series of laboratory tests and from the rock mass characterization in the mine drifts and mine tunnels, which allowed a RMR of 60 to be obtained for the embedding rock (micaschistes and gneiss) and a RMR of 35 for the talc mass.

From this characterization, the geomechanical properties were defined (Bieniawski, 1989; Brady & Brown, 1985; Hoek , 2000; Hoek, Carranza-Torres & Corkum, 2002). The stress-strain law was an elastic ideally plastic law and the yielding criterion was the Mohr-Coulomb one. The fill properties used in the models was defined starting from the admissible uniaxial compressive strength which is the parameter that can be easily controlled in the mine. Two different values were considered in the first set of the models: 10 MPa (type 1) and 6 MPa (type 2). Only the type 1 was applied in the second set.

Numerical modelling results

The results obtained with the first set of numerical models show that the type 1 fill allowed a stable condition of the mine and the embedding rock mass to be obtained, even thought, a wide plasticization of the orebody mass was present after the exploitation of the seven levels and high stress values are located around the ramp tunnels

Table 1. Geomechanical parameters of the rock mass used in the model

Geomechanical property	Embedding Rock mass	Talc	Transition zone
Density [kg/dm^3]	2.6	2.75	2.6
Deformability modulus [MPa]	13300	860	670
Poisson ratio [/]	0.28	0.25	0.4
Peak cohesion [MPa]	4	0.18	0.2
Peak friction angle [°]	48.5	16	25
Dilatance [°]	0	16	25

and in the hanging wall near the 6th and 7th levels. In these models, the fill is mainly under compressive stresses. The type 1 fill is elastic throughout while the type 2 fill induces plastic zones in the 1st-5th levels and this can be an index of local stability problems during exploitation. The computed vertical displacements in the 1st and 2nd levels were larger than 1 m and these values are larger than those observed in other mine sectors.

This result allows to say that the chosen natural stress:

$$\sigma_v = \gamma \cdot h \text{ and } k_0 = 1$$

was probably too high to correctly model the Rodoretto mine. Therefore of models was developed to take into account the influence of the embedding rock mass and talc deformability on the natural stresses and the incomplete backfilling of the drifts. In the second set of models, the computed vertical displacements of the first level were 30-50 cm, at the end of the exploitation (Figure 6) and were consistent with the in situ observations in the other sections of the mine where the vertical displacements of the drifts during the development of the mine was never larger than 50 cm. To verify this data a sub-horizontal assestimetric device (29 m long) was installed in a drift at the 5th level. During the passage of the first drifts at the lower level a deflection of 15 cm has been measured in the middle of the drift.

This model was, therefore, chosen as the reference one and it was used to define the stresses acting in the fill and around the mine infrastructures:
The maximum vertical stresses acting in the contact points of the fill between the levels at the end of the exploitation were: 1st level: 3.0 MPa; 3rd level: 2.8 MPa; 5th level: 2.5 MPa; 7th level: 1.6 MPa. These values are lower that the admissible fill strength;

- the plastic zones in the fill and around the mine ramp are very small. The plasticity could only be critical around the lowest part of the ramp where it could easily be controlled by tunnel supports, such as bolts and/or steel arches;
- the stresses acting in the hanging wall and around the mine ramp did not induce critical conditions except for a vertical stress concentration between the upper portion of the ramp and the orebody.

Analitical model of the fill

The analytical models which were adopted to verify the local stability of the fill when mining a drift below a filled drifts were developed with the hypothesis that:

- the filled drift work as a loaded thick cantilever beam or as an arch of independent elements (Obert & Duvall, 1957), (Figure 7);
- the load computed with the second set of numerical models, was applied onto the beam: 1 MPa when the upper 3 levels are considered and 0.5 MPa for the other levels.

It was possibile to verify that for a uniaxial compressive strength of 10 MPa for the fill, the drift could be 6.5 m large with a load of 1 MPa and 9 m large with a load of 0.5 MPa.

CONCLUSIONS

The Fontane mine (Prali, near Torino in the North-West of Italy) has used a cut and fill descending slices with the cemented fill since 1974. When the new Rodoretto orebody was started to be exploited, a detailed numerical study was focused on the definition of the minimum acceptable strength of the fill and a laboratory test campaign was conducted to verify the possibility of using the mine wastes. The analytical and numerical modelling results suggested that, to guarantee the stability of the filled drifts, when excavating downwards and to maintain adequate stability conditions of the whole orebody and mine infrastructures, the compressive strength of the fill should be no less than 9-10 MPa and that the length of the unsupported filled drift

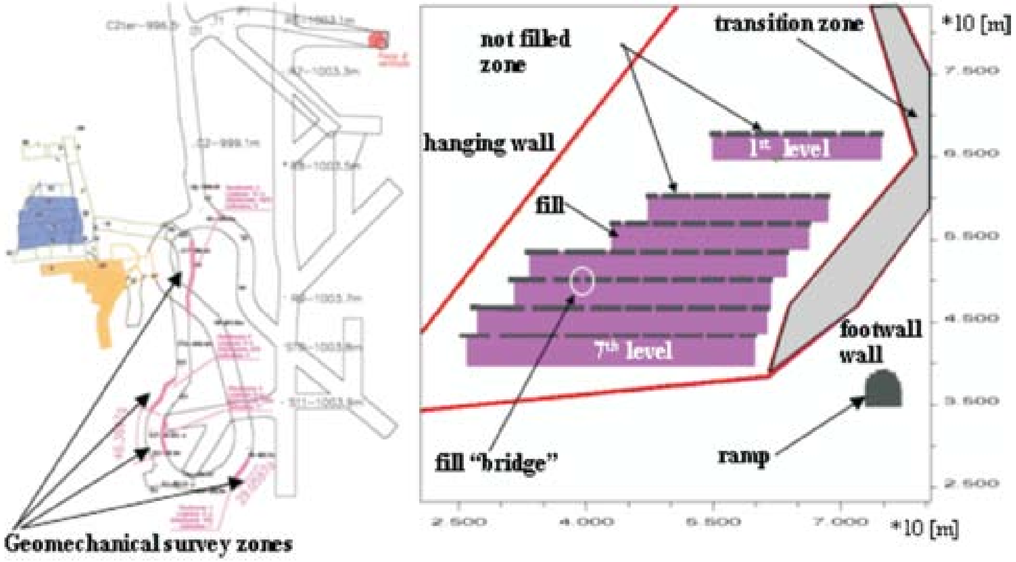

Figure 5. Plan of the south Rodoretto mine with indication of the filled drifts (1st and 2nd levels) in May 2003 and with the position of the geomechanical survey along the mine ramp (on the left) and the scheme of the partial filling of the mine adopted in the second set of numerical models (on the right)

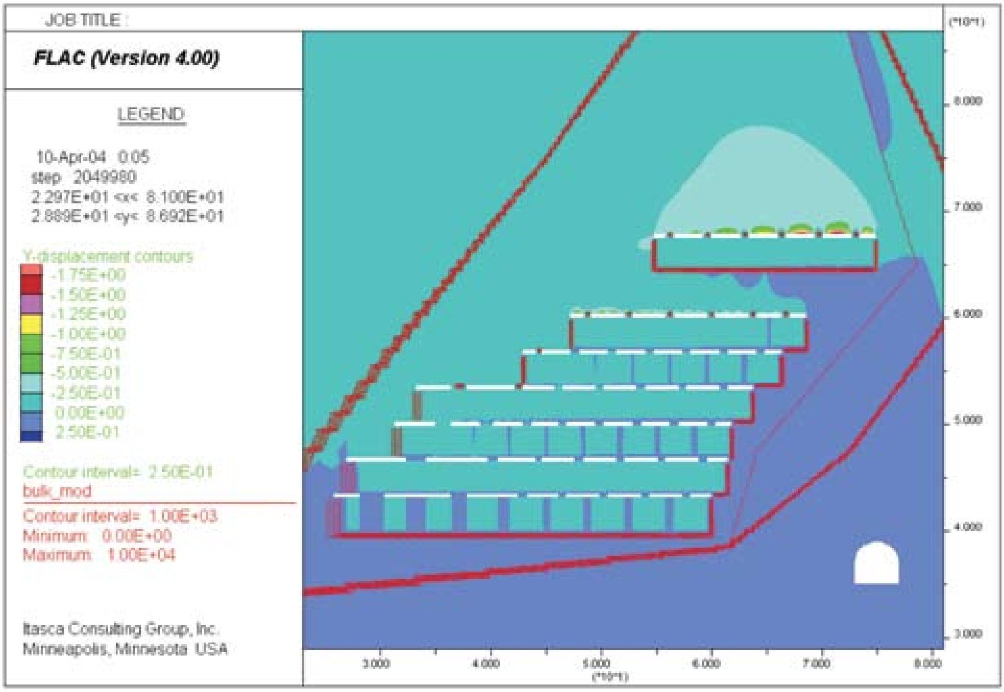

Figure 6. Vertical displacements at the end of the exploitation in the second set of models with a type 1 fill. Vertical displacement of the alignment AA at different distances (*d*) from the roof of the 1st level – the positive displacement (δ_{yy}) are in the direction of the arrow.

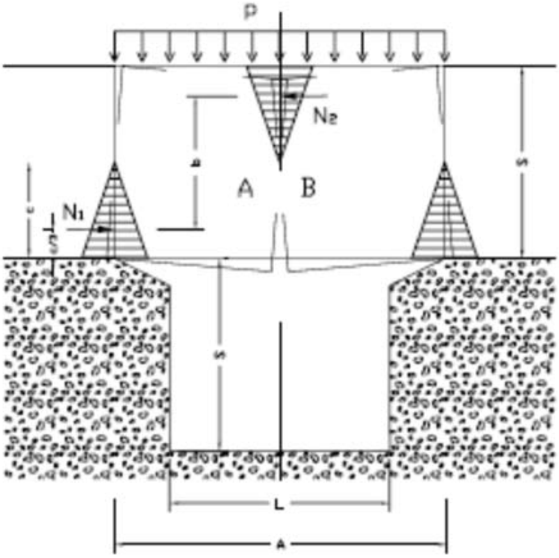

Figure 7. Analytical scheme of the arch made up of independent elements

below the backfilled drifts should be no longer than 6 m.

The stability of the levels was also checked by some topographical measurements and the monitoring of a cemented drift by an assestimetrical device which gave results in good agreement with the numerical modelling.

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