Numerical approach to design the support of galleries at great depth

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ABSTRACT

The use of the same gallery to serve two working faces has obvious economic advantages. At great depths, however, the behaviour of roadways deteriorates and the constant timbering which has to be undertaken is not always very appropriate. A combination of measurements taken in situ and numerical modelling has made it possible to determine the main mechanisms behind the deformation of these roadways. On this basis, two modifications of their support have been tested numerically using UDEC software.

1. SITE DESCRIPTION

The coal workings concerned are those of U.E.Provence mines (part of Charbonnage de France group), located in the south-east of France, 10 km north of Marseille (Fig. 1).

The investigated zone lies in front of a tectonic thrust wedge and is bounded by the *Diote* fault and *Safre* thrust fault. Highest density of faulting lies southward in the vicinity of the *Safre* fault : this zone has directly undergone the compressive load exerted by the thrust sheet. Also, the geological history is responsible for the present state of stress, the variation of the physical and mechanical properties of the calcareous bed, and the geometrical arrangement of the major faults planes. The principal fault planes may have an influence on the behaviour of the strata, through their geometrical characteristics, especially if their effects combine (Gaviglio et Al. 1996).

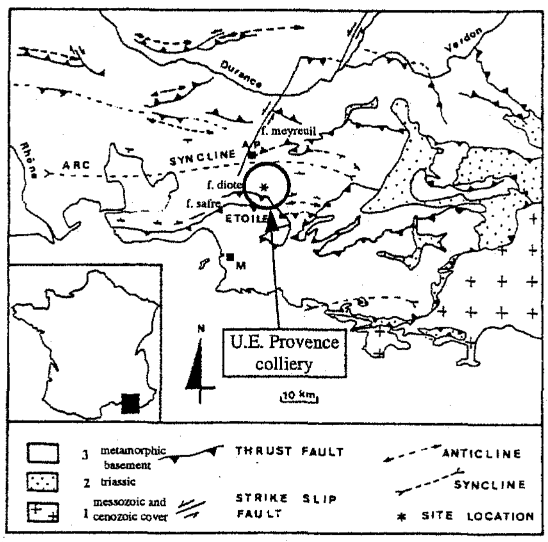


Fig. 1 : Structural sketch of Provence

Tunnelling under Difficult Conditions and Rock Mass Classification,
Bâle, 27-29 octobre 1997, p. 187-195

At the centre of the deposit, in the part being worked, the inclination of the seams is relatively small (some ten degrees). The workings are at a depth of approximately 1100 m.

The opening of the worked seam varies between 2 and 3 m. The composition of the seams remains constant over the entire workings (Fig.2). The coal is mined by the longwall method (Fig.3).

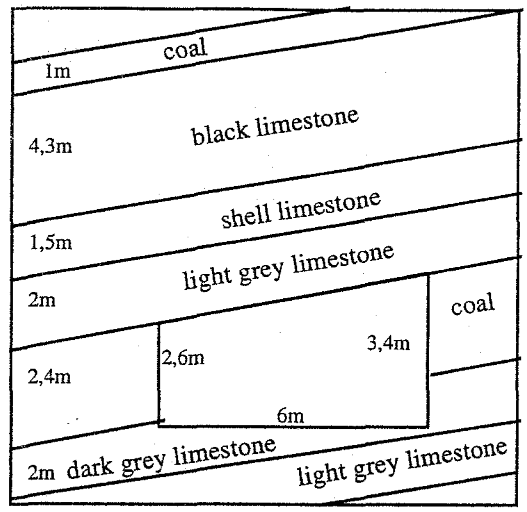


Fig. 2 : Lithologic section of mine

The excellent behaviour of the limestone at the roof of the worked seam has made it possible up to now to re-use the old lower gallery (main gate) as the upper gallery (tail gate) for mining the new face (Fig.3) and to avoid having therefore to drive a new roadway. Measurements of the stresses taken in the workings concerned here have shown that vertical stress is fairly close to the weight of the overburden ($\sigma_v = 27$ MPa). Anisotropy of the stresses is observed in the horizontal plane, the major stress being perpendicular to the axis of the road ($\sigma_H = 40$ MPa and $\sigma_h = 20$ MPa) (Gaviglio et al., 1996).

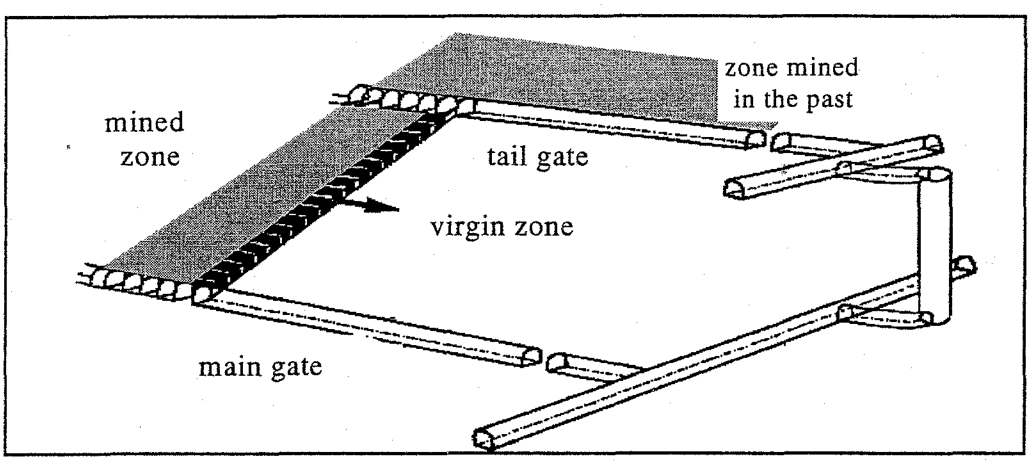


Fig. 3 : Longwall mining method

The support used for the drifting of the galleries consists of 2.2 m bolts resined over 1 m length (with a density of 1 bolt per m^2). Before the passage of the working face (200 m before) 2 additional 4 m long bolts are installed as well as metal frame. After the passage of the working face a double row of timber pillars comprising crossed beams of 1.1 m x 1.1 m is installed between the gallery and the workings (Fig.4).

2. DESCRIPTION OF THE DEFORMATION MECHANISMS IN THE GALLERY

2.1. Underground observations

Before the passage of the working face, deconsolidation of the roof is observed which tends to cause detachment of blocks. As the working face is being passed, the convergence increases, and numerous bolts are close to rupture in extension (visible deformation of the plates). Tilting of the roof is observed along a subvertical fracture, caused by the workings, located at the unworked side of the gallery (virgin side).

2.2. Measurements carried out

A serie of measurements was carried out in the workings with the purpose of defining the behaviour of the roadway during the course of the advancement of the longwall face. Measurements of convergence, expansion and roof tilt were made as well as pressure measurements in the bottom face and in the timber pillars (Fig.4).

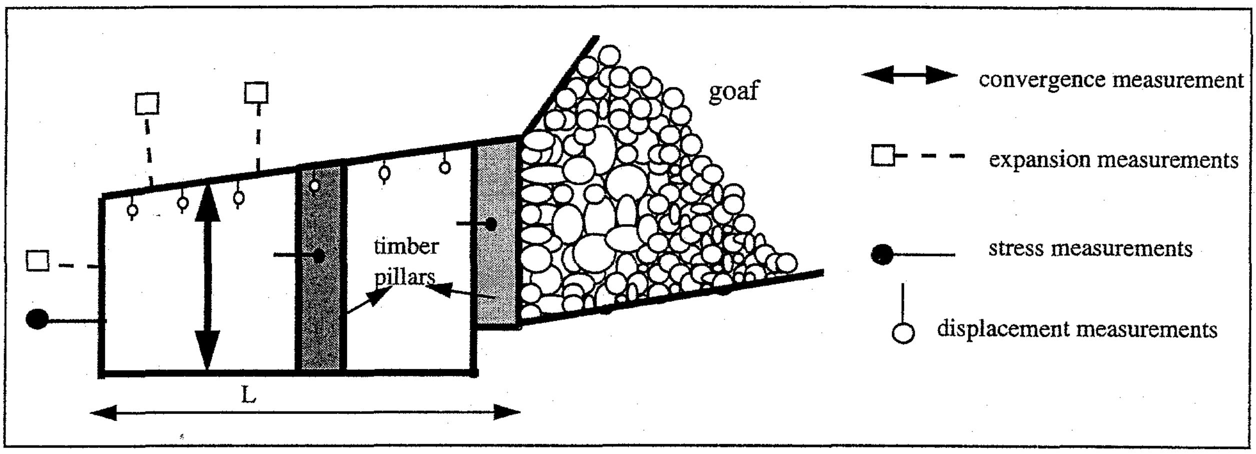


Fig. 4 : Monitoring station in the gallery

2.3. Design of a representative model

With the in situ measurements it was only possible to describe what was accessible to the investigation. To obtain a better understanding of the mechanisms involved in the very heart of the workings our aim was to design a three-dimensional numerical model (using the 3DEC software) (Thoraval, 1996). The model has made it possible to include the main stratification joints, to take account of the different working phases and the treatment of the galleries after the passage of the longwall face.

2.4. Results

It can be seen in Fig. 5 that the curves for the measured and calculated convergences are similar. The convergence as the longwall face is passed varies in the two cases between 300 and 400 mm. This convergence reaches approximately 1,1 metre, after the working face is passed.

Fig. 6 shows the trend in the deformation of the roof (tilt) according to the position of the longwall face. Before the passage of the face the tilting is towards the virgin areas. After the passage of the face the tilt is reversed and manifests itself on the side of the empty worked space.

The strong convergences found in the roadway are prejudicial to the normal advancement of the face.

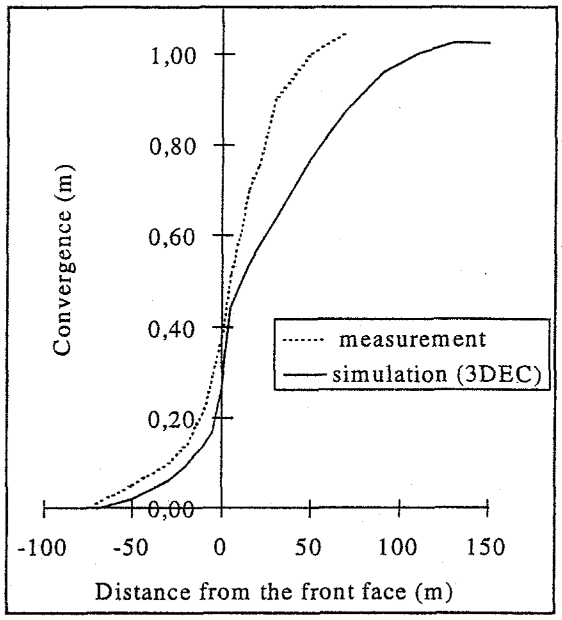


Fig. 5 : Convergence evolution of the gallery

Analysis of the mechanisms shows that the convergences are the result, at one and the same time, of a loading of the two sides of the roadway and of the tilt of the roof. A reduction in the convergence could therefore be obtained by reducing the width L of the gallery after working (cf. Fig.4) by removing one of the two rows of timber pillars at the edge of the worked zone and by installing extra anchor support systems at the non-worked side of the gallery.

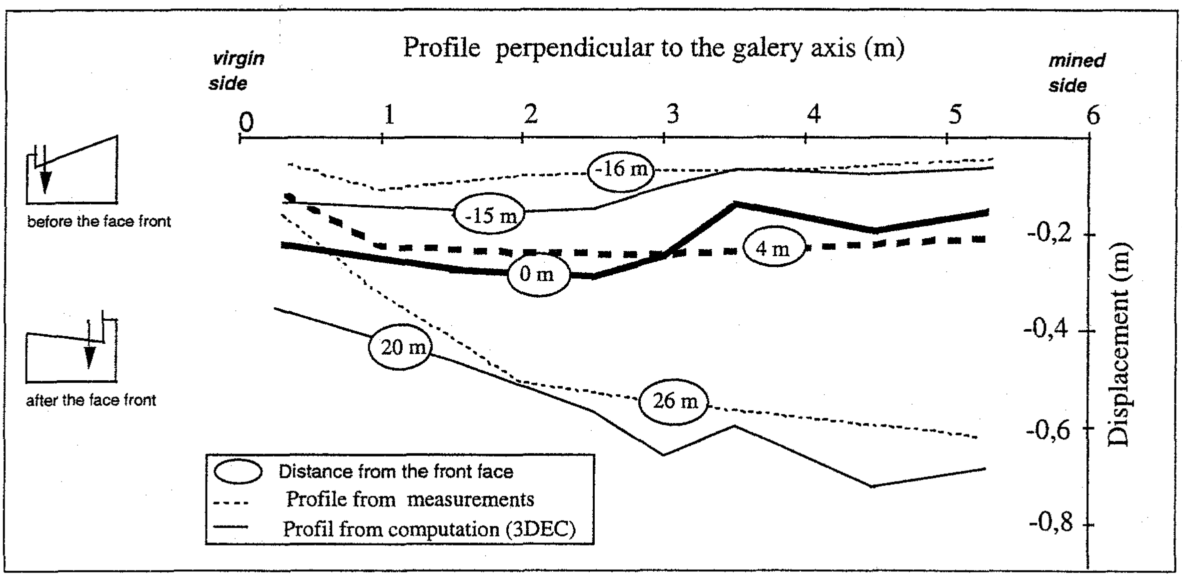


Fig. 6 : Evolution of the gallery roof deformation

3. IMPROVEMENT OF THE PREDICTIVE MODEL

The very long time taken to make the calculations for the three-dimensional model (at least two months calculation for a simulation) means that new supporting methods for the roadway cannot be tested quickly. For this reason we investigated a method which makes it possible to simulate, in 2D, the advancement of the face by modelling the subsidence by a progressive destressing of the burden. This method is similar to the one used in civil engineering for the digging of tunnels (Panet, 1995).

3.1. Setting the predictive model

The entire history of the roadway has therefore been simulated in this way - from its excavation to the working. The modelling covers three stages: the excavation of the gallery, the influence of the working face before and after its advance.

- *Phase 1 - Modelling of the excavation of the roadway*

To model the advancement of the excavation in 2D, we adopted an analytical solution which boils down to simulating the contribution of the face by applying a decreasing confinement pressure over the circumference of the gallery. The model was set up initially from the deformation measurements carried out at the excavation, by adjusting the Young's modulus of the burden and the plasticity thresholds.

- *Phase 2 - Modelling of the effects of the approach of the working face*

To simulate the effects of the excess stress which precedes the working face, a vertical excess stress is applied to the upper part of the model, face side (maximum value applied: 2.5 σ_v).

- *Phase 3 - Modelling of the influence of the working face after it has been passed*

The two rows of pillars are introduced at the back end of the roadway. The subsidence in the working face is simulated by a progressive destressing of the roof and wall of the face (Fig. 7). Also simulated is the progressive degradation of the roof burden due to fracturing (natural or induced). The degradation schema was chosen so as to simulate as closely as possible the deformations measured at the moment the working face was being passed (second setting).

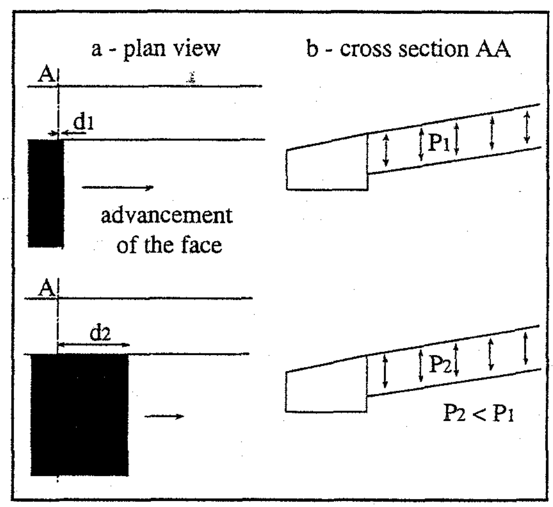
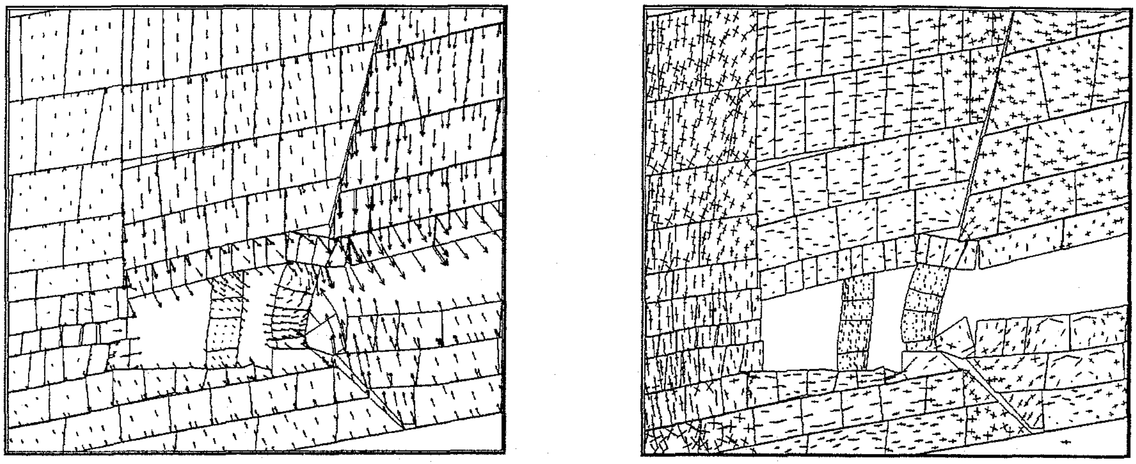


Fig. 7 : Modelling of destressing

3.2. Modelling of the current treatment (modality 1)

The mechanisms found are : the throw of the subvertical fracture occurring at the bottom edge of the gallery; the separation of certain stratification beds in the roof of the roadway and the block dislocation in the roof and wall of the worked face (Fig. 8).



displacements vectors principal stresses

Fig. 8 : Mechanism simulated by the model

The displacements in the galleries caused by the excess vertical stress prior to the arrival of the face (phase 2) remain less than 200 mm.

On the basis of the values measured, a relationship has been established between the confined pressure imposed and the distance from the working face which makes it possible to find the three-dimensionality of the problem.

Fig. 9 illustrates the trend of the convergences in the roadway as well as the throw of the subvertical fracture. The calculated maximum throw (0.35 m) is reached very quickly after the passage of the working face.

Fig. 10 shows that the maximum vertical stresses are 12 MPa in the pillar situated in the middle of the roadway and 6 MPa in the edge pillar. These values are close to the values measured in situ, i.e. 14 MPa and 8 MPa respectively (Thoraval, 1996).

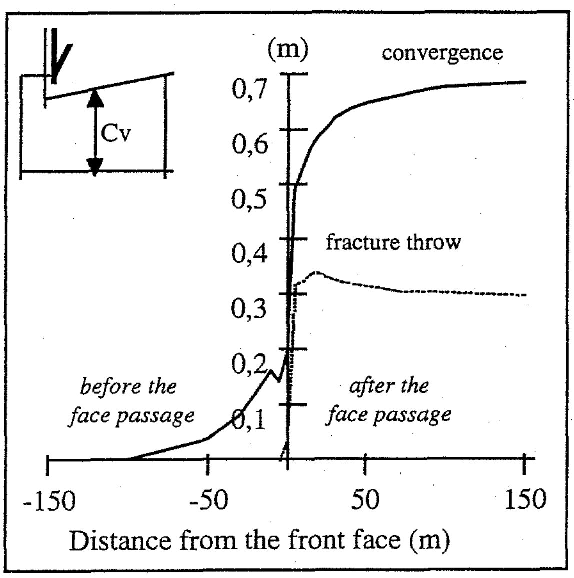


Fig. 9 : Evolution of the gallery convergence

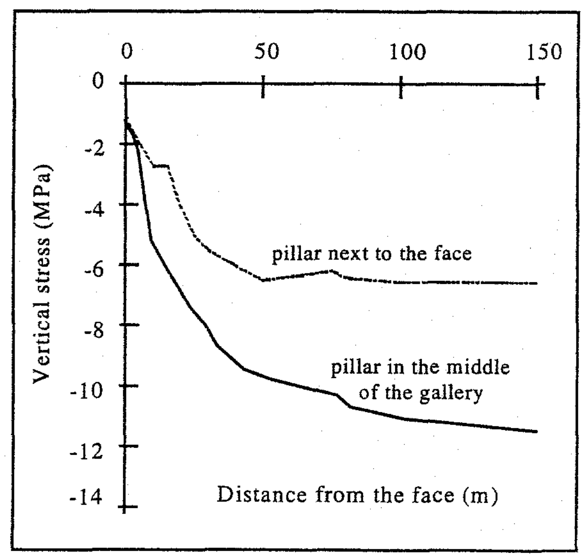


Fig. 10 : Evolution of the vertical stress in the pillar

4. PROPOSAL FOR MODELLING THE BEHAVIOUR OF THE GALLERY

The model having now been set, it is possible to interrogate it to try out modifications of the treatment of galleries to improve their behaviour. Two additional methods have been simulated.

4.1. Removal of the row of pillars at the edge (modality 2)

To minimise the convergence in the roadway it was proposed that the width L of the gallery should be reduced after working by removing the row of pillars at the edge of the roadway. Fig.11 shows that the calculated convergence decreases by about 7% when this row of pillars is taken away. The difference is bigger for the throw of the subvertical fracture which decreases by about 30%.

4.2. Installation of cemented cables at the bottom side of the roadway (modality 3)

In order to reduce the tilt of the roof of the gallery it is proposed that 2 cemented cables (of the "double-birdcage cablebolt" type - see McDonnell, 1995), 5 to 7 m long and oriented approximately 60° to face of the unworked side, should be laid at every metre of the gallery.

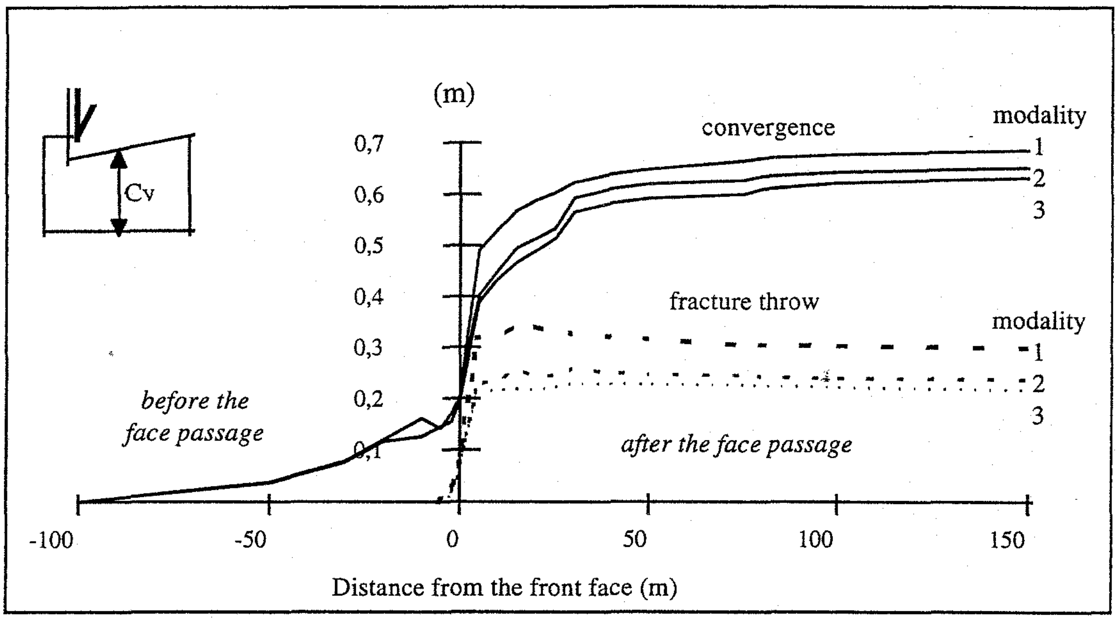
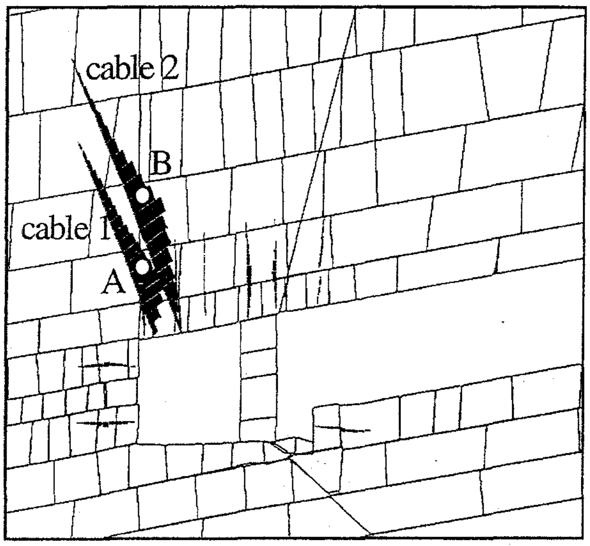


Fig. 11 : Roof displacement for the three modalities

The characteristics of the cables are as follows: Young's modulus of the steel = 210 GPa; density = 80 kN/m^3; ultimate tensile strength (elastic limit) = 600 kN ; maximum strain = 20% ; tangential rigidity of the grout sealing = 40 MN/m/metre of cable ; cohesion of the grout sealing = 3 MN/metre of cable.

Figs. 12 and 13 give curves for the evolution of the axial forces and strains respectively. The maximum values are reached at the level of the intersection with the subvertical fracture (points A and B)



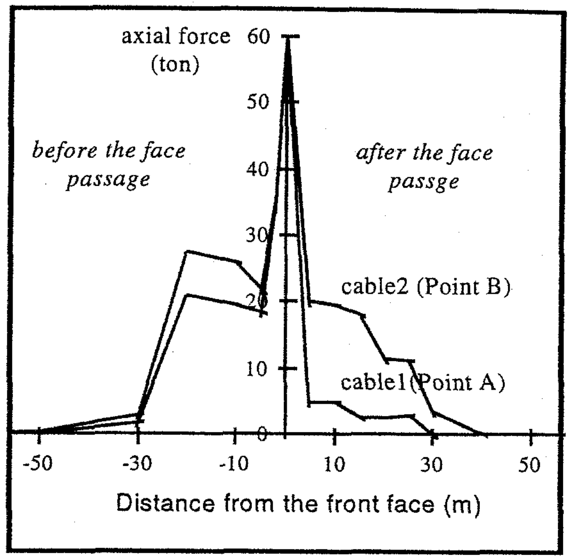


Fig. 12 : Evolution of cable axial strength

A sharp increase in the axial force is found in the cables at the moment the face is passing. The axial force then falls rapidly to disappear after the face has been passed. The axial deformation of the cables decreases slightly immediately after the passage of the working face (elastic part of the preceding deformation) then remains almost constant (irreversible plastic part of the deformation).

The laying of 2 cemented cables at the bottom side of the roadway (modality 3) contributes towards reducing the convergence in the roadway by 5% and the throw of the subvertical fracture by 12%.

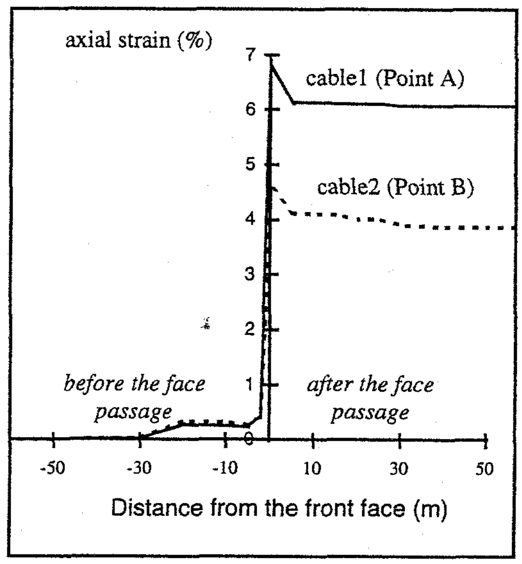


Fig. 13 : Evolution of cable axial strain

5. CONCLUSIONS

A serie of measurements taken in situ has made it possible to describe the behaviour of the burden in the vicinity of a road at great depth (1100 m). The degradation mechanisms have been clearly identified such as the appearance of a subvertical fracture in the roof, at the unworked side of the gallery, the tiling of the roof along this fracture and the deformation of the pillars as the working face is passed. These phenomena have been well simulated by a representative three-dimensional model implemented with 3DEC.

A two-dimensional UDEC model, taking due account of the three-dimensionality of the problem (advancement of the face), has also been implemented in order that the effects of a change in the treatment of a road can be tested more quickly. Its use has shown that reducing the width of the roadway after working brings about a reduction in the convergences and in the tilt of the roof.

The installation of two cables at the bottom side of the road reduces the tilt even more. The model predicts a major loading of the cables during a fairly short phase which is interrupted after the goaf has started.

ACKNOWLEDGEMENT

This study was commissioned by U.E. Provence who supplied us with the necessary data and cooperated fully with our ideas on how to improve the support of galleries.

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