Observation and auscultation of the geotechnical behaviour of a slope in an open cast mine influenced by old underground mining (South-western part of France)

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ABSTRACT : The final slopes of a French open pit mine of the "Charbonnage de France" company which final depth will be 300 metres, have been designed after a standard geotechnical survey. This one has taken into account the geomechanical, hydrogeological, structural parameters as well as the "decohesion", induced by former mining subsidence. However some slopes can locally present risks of slipping (increasing with the depth of the pit) induced by old underground mining.
A methodology has been defined concerning the slope auscultation and its behaviour including the use of numerous measuring tools (topographic measurement, inclinometer, equipped cable bolts...).
Two auscultation cases are presented, one on a slope slipping, another one on a potential slide. In the first case, the instrumentation checked that the reinforcement is satisfactory. In the second case, the instrumentation allows to analyse that the correct measures have been taken to prevent any risk.

1 - INTRODUCTION

The Sainte Marie open pit is a coal mine of the Mining Unit of Tarn, H.B.C.M. (Houillères du Bassin Centre Midi), in the south-western part of France, near Albi (Fig. 1). In this area a large amount of coal has been exploited by underground mining. This pit was designed in order to exploit the coal remaining around the shaft (Saint Marie shaft) of an old underground mine situated in the basin of Carmaux.
The diameter at the top of the pit is 1200 metres and its final depth will be 300 metres. The first 100 metres are composed of tertiary deposits (clayey sand) which covered the carboniferous formation. The average slope angle of the Tertiary is 37° (without benches) and in the Coal Measures it was foreseen from 37° to 50° (with benches of 6 metres high) depending on the slope situation. At present time, the depth of the mine is about 160 metres.
Nine coal seams (named form the top : C, D, DT, F, E, G, H, I, J) have been mined by underground working between 1900 and 1984. Different methods have been used depending on the thickness, the dip of the layer and the dimension of the panel. In fact panels were backfilled, caved or undermined long-wall.
The basin of Carmaux is a large synclinal split by a dense network of faults which directions are approximately N 140 E. The dips and the dip directions

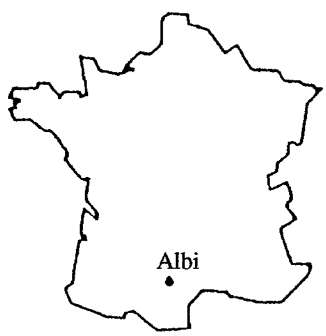

Fig. 1 : Situation

of these principal normal faults are quite variable because of a complicated succession of tectonic phases. The throw of the faults oriented N 140 can be from 20 to 100 metres, and the spacing is from 10 to 100 metres. This particular network of main faults leads to consider the basin as a succession of narrow compartments.
The structure as a large influence on the slopes behaviour. In fact the centre of the open pit is composed of unexploited layers of coal, because it is the coal

Australian Conference on Geotechnical Instrumentation and Monitoring in Open Pit and Underground Mining, Kalgoorlie, 21-23 juin 1993, pp. 427-433

which was left around the shaft, but, close to the slopes, begin the old exploited long walls. These long walls are at different topographic levels due to the particular structure and have been exploited in panels lined by the faults oriented approximately N140 (Fig. 2).
The first design of the open pit was done by a standard geotechnical surv ey; this one has taken into account the geomechanical, hydrogeological, structural parameters as well as the "decohesion", induced by the revival of subsidence due to old underground mining. However some mining slopes can locally present risks of slipping induced by old underground mining.
We shall present, at first, the different kinds of instruments installed in the mine, then we shall focus on two cases : one on a slope slipping, another one on a potential slide.

2 TYPES OF INSTRUMENTATION

As far as a lot of the equipment is well known, we shall briefly describe the principal types of instrumentation and only insist on the ones which may be more unusual.

2.1 *Topography*

About 60 topographic points are installed all around the mine. These topographic plugs are more numerous in the areas where slope stability problems were detected. When there is no particular problem the position of the points are monthly collected. In case of movement the monitoring is more frequent and it can lead to make two measures a day when a sliding has been detected (cf. §3).
The topographic survey is done with the help of a T 2000 theodolite «Distomat Wild». The plugs are fit out with prismatic reflector. The accuracy is 1/10000 grades for the angles and 5 mm added to 5 mm/Km for the distances.

2.2 *Inclinometers*

Ten vertical inclinometers with depth going from 35 to 70 meters have been installed in the mine. The inclinometers are localised were slope problems were detected. We shall present the measures of this equipment with the description of instabilities.

2.3 *Extensometers*

Some rod extensometers (Wr-Flex) are set in boreholes. In general, the equipment we use, has 5 anchor points, 5 metres away from one another, so the total length informed is 20 metres. The first anchoring point is generally at about 20 metres from the surface. The extensometers are vertical or tilted and are manually measured.

2.4 *Shear strip*

The shear strips which are used and that we call «breaking tube» (made by INERIS) are composed of electrical resistances regularly positioned (in our case each 50 centimetres) and linked with two copper ware wires. The all package (electrical resistances and wires) is included in a PVC tube filled up with glass spheres and resin. An element of shear strip has 12 metres long and it is possible to put several elements linked to each other in a hole. Two measures can be made : one from the top and the other one from the end of the tube. In case of movement, the shear strip is broken and the measure of the resistance of the tube falls down. As electrical resistances are installed each 50 centimetres, we can localised a rupture with this accuracy.

2.5 *Tension-measuring gauges*

When cable bolts are installed in order to reinforce the slope, some Tensmeg-70 gauges (Supportek Inc.) are used. The working principle of the gauges is based on the change of the resistance of the resistance wire caused by cable elongation. Calibration tests have shown that there is a linear relationship between readout values and tension applied to the cable. The value of resistance allows to know the tension in the cables.

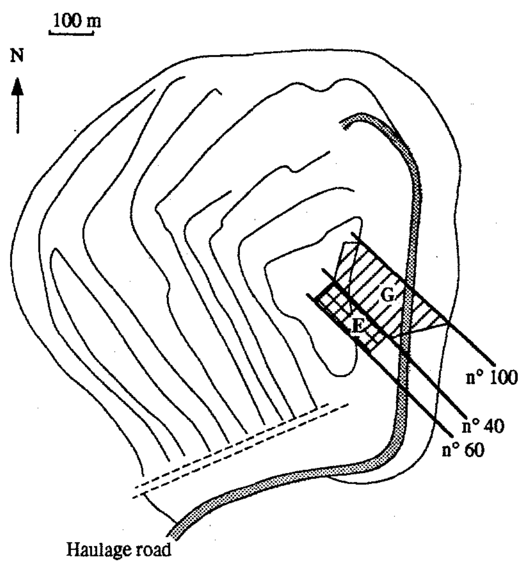

Fig. 2 : Schematic map of the open pit

3 MONITORING OF A SLOPE SLIPPING

In July 1990, after a topographic reading, the beginning of a movement was detected at the interface between Tertiary and Stephanian (by the displacement of the spot 500) in the east part of the open pit. At this place the pit was 150 metres deep and 4 benches of 6 metres high, of Coal Measures were mined. Opened cracks were detected in the haulage road (Fig. 3) above the plug 500.
The analysis of this movement and the information from the underground mining, show that the sliding mass was just above an exploited panel of the E seam (Fig. 2) and was delimited, in the coal bearing ground, by two faults : in the north, a fault oriented N 150 E, W 55, named n° 40, and in the south a fault oriented N 125 E, N 44, named n° 60 (the number of the fault was assigned during the underground mining). The panel of the E seam was a long wall exploited in 1960 and backfilled with shales without any cohesion.

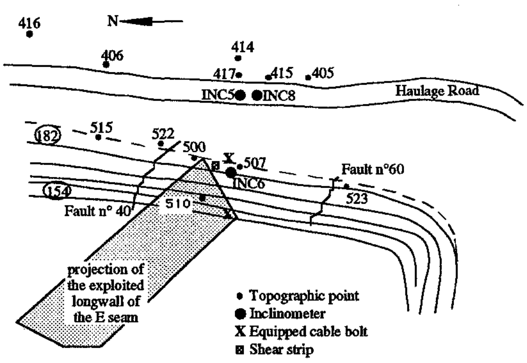

Fig. 3 : Map of the east slope above the E seam

The movement was finally stopped by constructing a embankment-buttress, 35 metres wide and 40 metres high.

In order to monitor this sliding and verify the efficiency of the buttress, the following apparatus were installed (just after the detection of the movement) :

- different topographic points are in this part of the slope : n° 417, 500, 507, 515, 522... (Fig. 3);

- 3 shear strips in different holes, 45° tilted. They were respectively 10 to 22, 20 to 32 and 27 to 39 metres from the top.

- 2 cable bolts of 24 metres long (250 kN of ultimate tension load) equipped of 5 Tensmeg gauges. The first cable from the elevation 154 was 30° tilted, the second one, installed form the elevation 182, was 25° tilted (Fig. 4)

- 3 inclinometers : INC5, installed from the elevation 226 and 60 metres long, INC8 installed from the elevation 226 and 38 metres long (this apparatus replaced the INC5 after this one has been cut), INC6 installed from the elevation 182 and 40 metres long.

As it took ten months to build up the embankment-buttress to its necessary size, the movement was

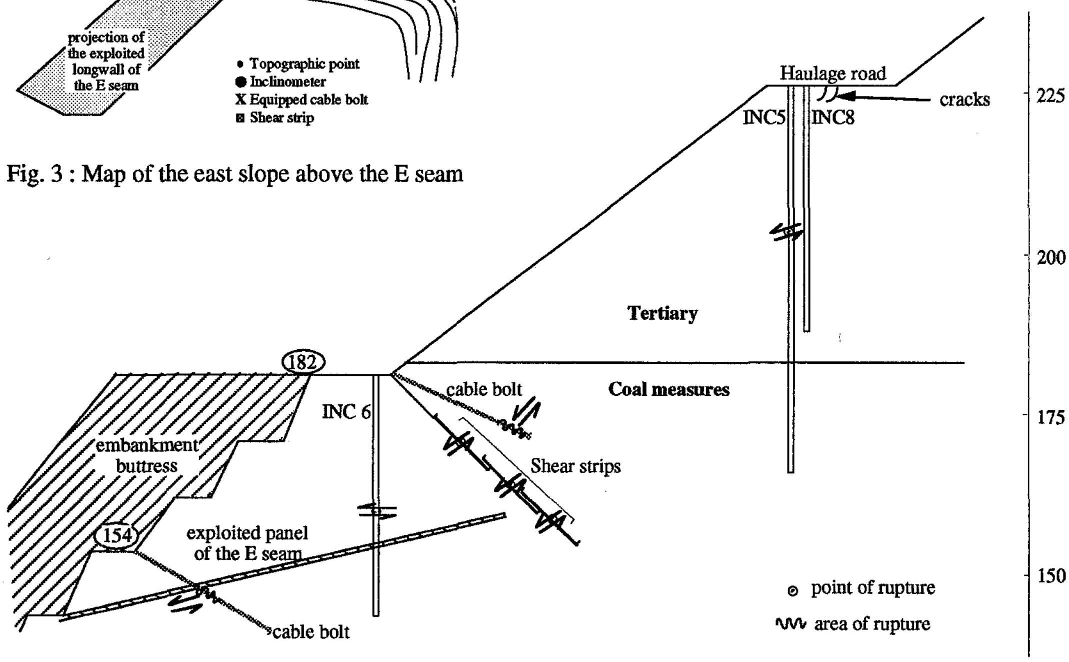

Fig. 4 : Section of the east slope through the exploited E seam

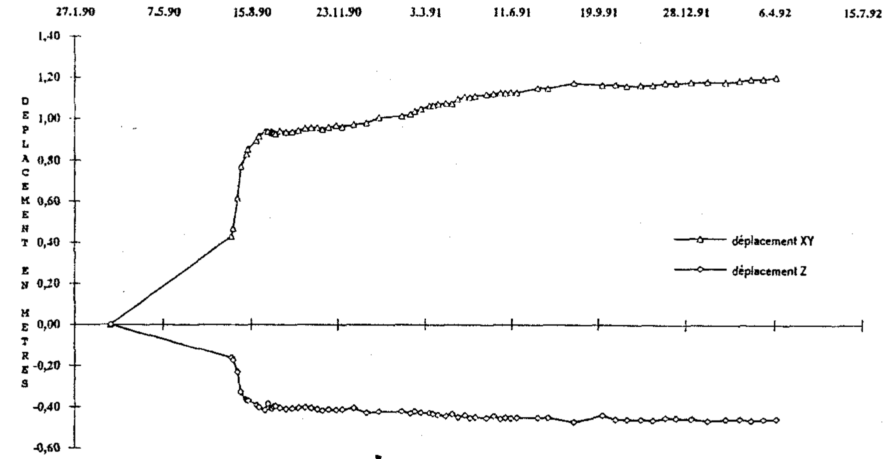

Fig. 5 : Time displacement (displacement in metres) of the point 500

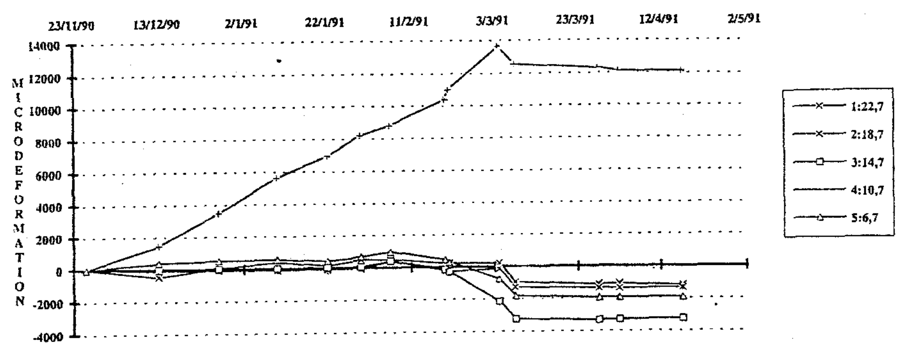

Fig 6 : Time evolution of the gauges of the cable installed from the topographic level 154

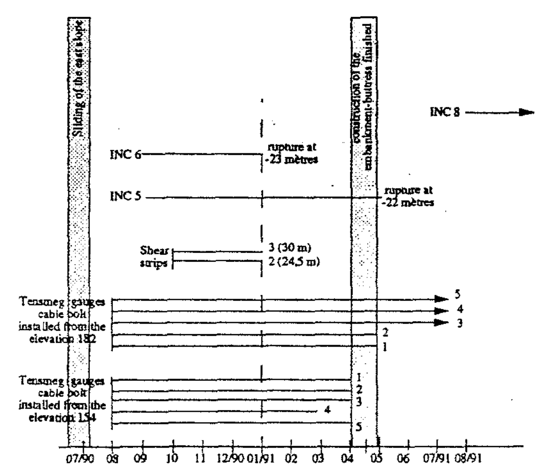

Fig. 7 : Time evolution of the monitoring

gradually stopped. The displacement of the spot 500 (Fig. 5) shows the time evolution of the movement. We can see that after the embankment-buttress was finished (May 1991), the displacement was less than a few centimetres. Most of the apparatus has shown an important activity of the slide between July 1990 and May 1991. The phenomena is shown by failure of shear strips, deformation of the inclinometers, values of the gauges (Fig. 6) on cable bolt which indicated that the load have exceeded the ultimate strength of the cable : 250 kN (in general the failure of the cable bolt arrive for 9000 micro strains). The time evolution of the phenomena is summarised in the Fig. 7. After May 1991, we can control that the movement was stopped, because the evolution of the topographic points is very weak and the inclinometer INC8, installed in August 1991 was not deformed.

The monitoring shows that the slickenside was effectively composed by the E panel and by a curved surface in the Tertiary formation, just under the haulage road. Different levels of rupture were detected. They

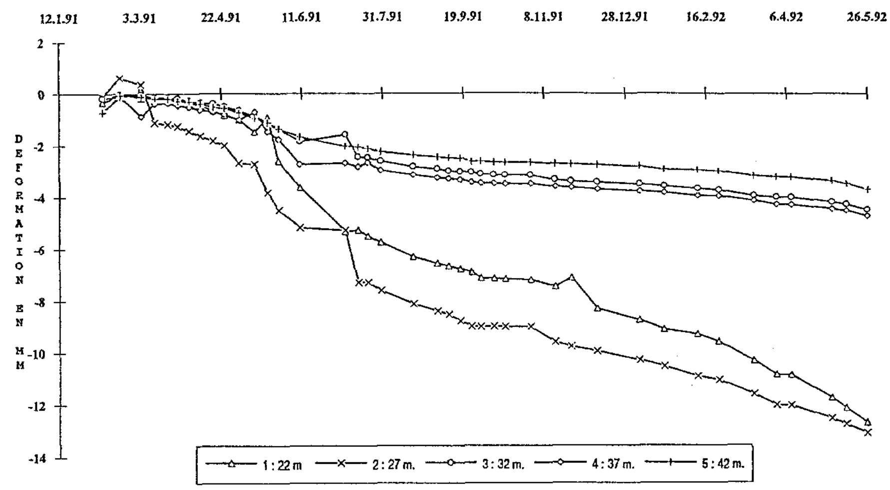

Fig. 8 : Time evolution (displacement in mm) of extensometer N° 1

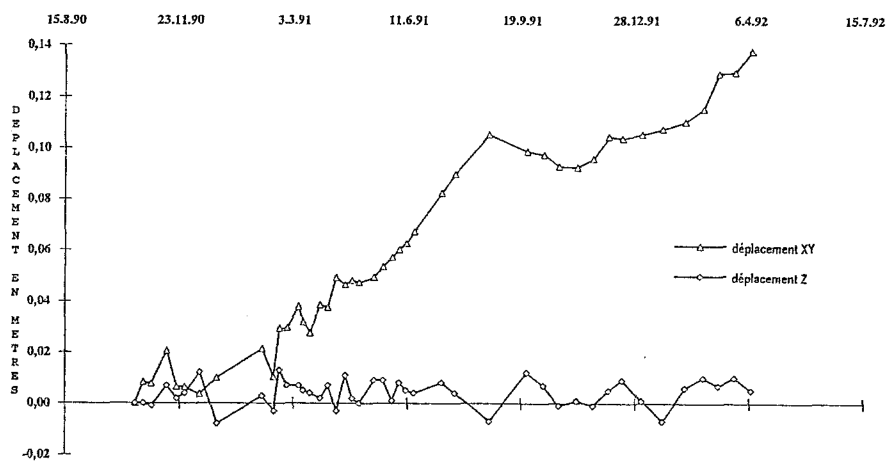

Fig. 10 : Time evolution (displacement in metres) of topographic point 515

Table 1 : Monitoring of the G seam

Apparatus	date of installation	Elevation of installation	depth of the borehole	inclination of the borehole	depth of the monitored points	Movement
shear strip	06/91	154	35 m	vertical	23 to 35 m	no rupture
Extensometer N°1	02/91	182	42 m	45° tilted	22, 27, 32, 37 m	down moving of the about 1 cm of the points 22 and 27 metres deep (begin in 11/91)
Extensometer N°2	07/91	154	40 m	vertical	20, 25, 30, 35 and 40 m	up moving of the anchor points 20 and 25 metres deep
Inclinometer INC7	10/90	182	50 m	vertical		cut at 22 metres (11/05/92)

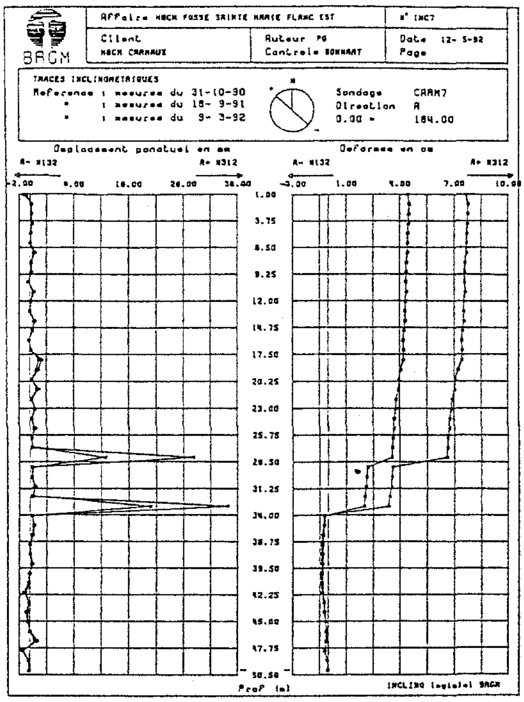

Fig. 9 : Deformation of inclinometer INC7 in May 1991

showed that the sliding mass was deformable, and that the movement cannot be modelled as an undeformable volume. A modelling has been made with the UDEC code, it showed that low cohesion of the backfill of the E seam and the network of fault can explain the extend of the slide.

By now the area is still monitored; no important displacement has been detected since 1991.

4 AUSCULTATION OF A RISK

In the north of the slide, we described previously, there was another configuration quite similar : between the two faults N° 40 (north limit of the previous phenomena) and n° 100 (N 117 E, NE 48), a panel of the G seam has been exploited in 1960 (Fig. 2). The dip direction of the exploited seam is, as in the previous case, oriented to the centre of the pit (the dip of the panel has the same direction as the slope). In order to make sure this configuration will not induce a slide, monitoring was installed (summarise in the table 1)

The auscultation of the G seam showed that there was a movement which progressed since May 1991. This movement has been detected by the topographic point 515 (Fig. 10), the extensometer N° 1 (Fig. 8) and the inclinometer INC7 which showed significant levels of deformation at 28 and 34 metres deep, in May 1991 and was finally cut in May 1992. Rod extensometers were very useful to detect movements under the slopes, increasing with the depth of the pit. Some reading are sometime difficult to explain because they are the result of different movement : revival of subsidence, settlement due to the embankment, shear movement on the old worked seam.

As the extensometer, the inclinometer and topographic points showed an acceleration of the deformation in this area, reinforcement was started up at the beginning of 1992.

In this case, again, in order to model the beginning of the movement and to calculate the reinforcement, we needed to take into account the result of the different kinds of monitoring, to have a better understanding of the movement. The results of this analysis lead to reduce the slope angle.

5 CONCLUSION

We analysed two cases of auscultation. In the first example, a sliding was detected by topographic measurements. In order to analyse the deformation and to understand the development of the movement, different kinds of apparatus were installed. In the second case a risk of sliding was detected by a geometric analysis and it was monitored.

Different kinds of monitoring system were used. The topographic measures represent a good alarm, which can detect a movement and allow to define the limit of a slide at the surface, but they cannot explain the mechanism of a slipping and the volume involved. The shear strips allow to detect a rupture, but they work only one time. The borehole extensometers show displacements, but the results of the measures are sometime difficult to explain when we have interference of subsidence, settlement and shear displacement. The inclinometer is the only apparatus which can indicate the direction of the movement. The tension-measuring gauges allow to verify the cable bolts are acting.

In order to have a correct understanding of a whole movement and to model it, we need to associate the different kinds of monitoring system.

By now, two other cases of potential problem have been detected. These configuration are a little different from the others because two superposed exploited seam will be cut by the slope. These cases will be monitored with the same kind of instrumentation.

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