Detection and characterization of underground cavities using high resolution seismic reflection (HRSR)

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DETECTION AND CHARACTERISATION OF UNDERGROUND CAVITIES USING HIGH RESOLUTION SEISMIC REFLECTION (HRSR)

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INTRODUCTION

Old underground mining works are subjected to risks of collapse of which the assessment is a complex process. In the case of inaccessible underground mines, the difficult task for the risk assessment is to classify the already collapsed zones (no further risk) from still stable structures which may collapse in the future. The knowledge of the characteristics of the underground cavities and hosting rock mass can provide relevant information. However, accurate underground cavities detection and characterisation based on geophysical techniques are still a scientific challenge in the subsoil prospecting domain. Among these techniques, the high resolution seismic reflection is the most successful in the frame of underground cavities detection.

The study presented in this paper, is a part of an extended research program aiming at prediction and controlling ground motions induced by underground cavities. The objective is to identify the most appropriate technique to localize and characterize the underground cavities at variable depths (several meters to 300 m). Thus, to meet these goals we have investigated the high resolution seismic reflection technique (HRSR). The selected test site is located close to Gréasque municipality in south France (figure 1). In this region, the underground works undertaken during the last two centuries consist of two mines: coal mine and cement stone quarries[1] (marl limestone). The geological setting is characterized mostly by coal layers and massive limestone formations of the upper cretaceous with alternated coal strata of variable thickness dipping westwards.

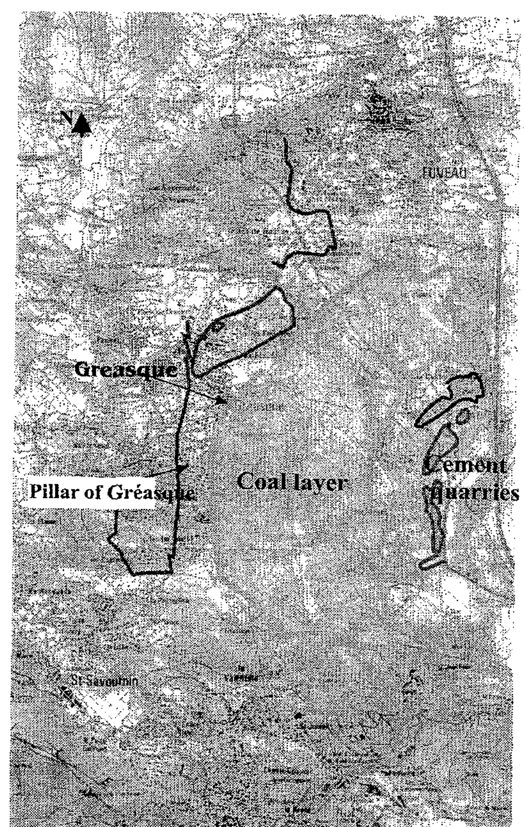

Figure 1: Location map of the test site, Gréasque, south France

[1] In this paper, shallow mine is assimilated to an underground quarry

This study addresses particularly the problem of the investigation of voids at depths varying from 7 to 20 meters in the cement quarry. The thickness of mined layers (i.e. expected voids) is about 2 meters.

HRSR EXPERIMENT

The HRSR data acquisition[2] was carried out using a Geometrics Strata View seismograph recording station, 100 Hz geophones and a silenced "Betsy gun" [1] firing 12-gauge hunting cartridges source. Three profiles A, B and C were carried out at ground level (Figure 2). The line C, purposely positioned mostly on an unmined part, is considered as a reference and allows the imaging of the natural geological structure. This information is used to interpret the cavities induced anomalies without ambiguities. In addition, this profile crosses two separate drifts in order to check the obtained lateral resolution.

The profile B crosses both mined and unmined zones; finally the line A crosses the total area of the quarry in N-S direction, but its CMP (Common Mid Point) resolution is two times smaller which implies worse quality of the seismic image.

The data analysis based on the common midpoint method (CMP), provided HRSR 2D sections imaging the crossed underground structures with a good signal to noise ratio. The geometry acquisition design parameters which have been chosen, regarding specific objectives and expected resolutions are summarized in table 1.

Table 1 : Geometry parameters of the seismic profiles carried out in the cement stone quarry

	Length (m)	Geophone spacing (m)	CMP spacing (m)	Exploitable frequency band (Hz)	Lateral resolution at 7 m (m)	Depth resolution ($\lambda/4$) (m)
Profil A	335	2	1	80-180		5.8
Profil B	105	1	0.5	250-400	3.15	2.3
Profil C	60	1	0.5	250-400	3.15	2.3

HRSR DATA ANALYSIS AND INTERPRETATION

The detection of underground cavities using seismic sections is based on the analysis of induced signal disturbances. The wave propagation through opened cavities implies time delay and masking effect on the underlying reflectors [2], [3]. In the case where the cavities are collapsed, the seismic response evidences total loss of signal coherence and an important drop in the signal level.

On the three sections of the profiles A, B, C shown on the figure 2, we clearly observe two main features: seismic responses of underground quarry and unmined structures. The HRSR image of the unmined structures appears as a succession of cement stone, limestone and coal layers (UM zones). The mined zone is characterized by non observed deeper reflectors (masking effect) and disturbances on the cement stone top layer reflections (MQ zones). In addition, all geological faults met during the cement stone mining are observed. The major faults detected in the northern and southern parts of the quarry (faults F1 and F4) probably implied the limitation of the underground works in those directions. The profile C evidences

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[2] Conducted by SOVEP, 59338 Tourcoing, France, 52 rue de Roubaix, http://www.sovep.com

unmined zone represented by the geological interfaces of cement stone, coal and limestone layers (CS, C, Lim); in the middle part, a fault (F3) is observed which has been probably the reason of the existing protection pillar (UCP). The seismic profiles A and B offer images of several cavities effects, in some parts of the sections the almost total loss of the signal suggests that the cavities are collapsed (CC). The roof of the cavities is located at the estimated depth of 15 m.
The anomaly CZ is identified on both profiles A and B and is interpreted as a collapsed zone. This interpretation has been validated and confirmed by the surface observations of the collapse (Rock cracks, ground subsidence). Another interesting seismic feature pointed out on the profile A is the relevant consistency with the underground quarry map, of the detected 15 m width pillar (UCP) structure which appears in the seismic section as the narrow zone of the continuous and undisturbed reflectors. This observation can be considered as resolution check of the HRSR imaging.

CONCLUSION

The high resolution seismic reflection applied to the underground cavities detection has been tested on the Greasque site (south France), characterised by old coal mines and cement stone quarries. The HRSR enabled imaging the underground structures at the depth range of 7-20 m with quite good resolution. The analysis of the seismic sections evidenced different features and anomalies associated with cavities effect and geological structures. In the quarry zone, the collapse observed at the surface has been clearly identified on the HRSR sections.
In addition, the seismic response of pillars and geological faults correlate quite well with their location on the (rough) quarry underground map.
Results from this experiment show that the HRSR technique is an interesting and efficient mean capable to evidence the presence of cavities and to recognise their state (already collapsed or not). However, to overcome the experimental limits, further modelling work and borehole check could be undertaken to refine the characteristics of the cavities and validate the HRSR interpretations.
The experimental feedback of the HRSR investigations in the frame of underground cavities detection and characterisation confirms its important contribution for subsidence risk assessment. Further investigations are being carried out by INERIS through its research programs aiming at developing an integrated procedure based on geological, mining and geophysical fundamental input in order to develop an elaborated a risk management methodology.

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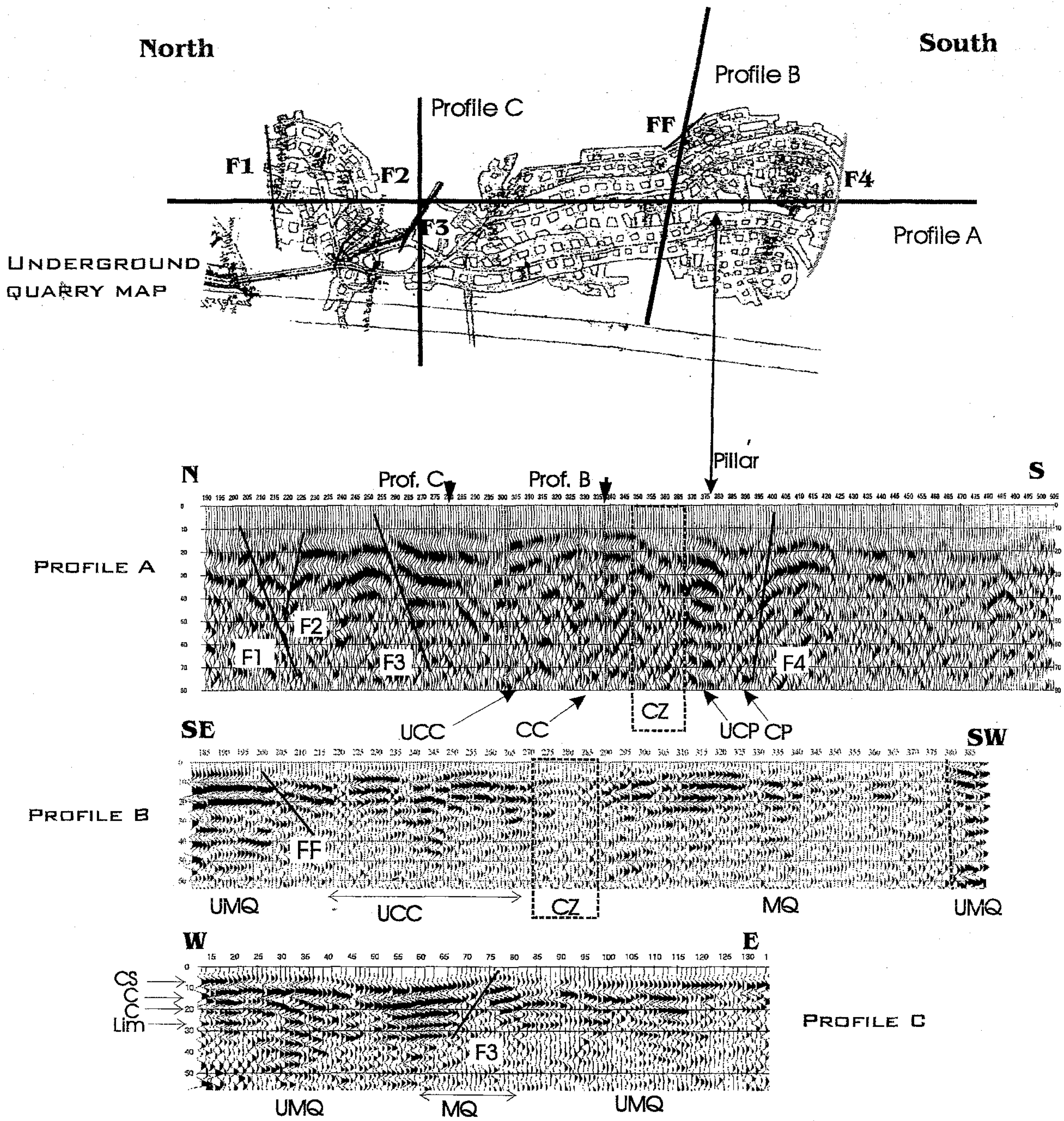

Figure 2: HRSR sections and interpretation.

MQ: *mined quarry*
UMQ: *unmined quarry*
CZ : *collapsed zone observed on the surface*
UCC: *uncollapsed cavity*
CC : *collapsed cavity*
UCP: *uncollapsed pillar*
CP: *collapsed pillar*
CS: *cement stone layer*
C: *coal layer*
Lim: *Limestone*
FF: *unknown fault*