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Detection of Underground Marlpit Quarries Using High Resolution Seismic

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This paper presents examples of application of high resolution reflection seismic for the detection and location of underground marlpit quarries in the region of haute-Normandie (north-west France) . Since some of these voids are unknown they represent a real danger both for population and building activities. The experiments are carried out at three sites with similar geological setting but differing in depth of voids (30-45 m), and in ground absorption (inelastic attenuation). For each site an explosive source is used. An additional survey is performed using new portable high resolution P wave vibrator, over one of the profiles. This provides an interesting comparison concerning the choice of the source type. In spite of high ground absorption and natural irregularities of the geological structure, the results show that the detection of marlpit underground quarries, often considered as unresolved, is possible.

Introduction

The achievement of good depth and lateral resolution of seismic image requires the use of short wavelengths i.e. high frequencies (the lateral resolution which express the ability to resolve two point targets spaced by is assumed to be equal to the Fresnel radius: $\delta_x = R_f = (\lambda d/2)^{0.5}$), $\lambda = V_{rms}/f_e$, V_{rms} is the stacking velocity and f_e is the exploitable signal frequency). Since ground absorption increases with frequency, f_e is always limited. According to the general principle, the increase of f_e requires powerful and wide band sources (i.e. emitting very short pulses. However, the latter condition limits radiated energy and the above requirements are contradictory. Finally, the obtained resolution is generally "imposed" by the ground absorption and is always a function of the propagation velocity. The detection of shallow tunnels and voids using High Resolution Seismic (HRS) involves the same type of considerations but additionally; the limited size of researched targets induces other problems:

1. If the size T of detected target is close or smaller than wavelength λ, the geometrical reflection practically does not exist and is replaced by a "diffraction",
2. If T/λ. ratio decreases, the diffractions originating from target limits (i.e. edge waves) can even cancel each other. Finally, the diffraction signal tends towards zero when T/λ. tends towards zero.
3. In order to increase the reflected signal level for a given target size T, the only mean is to decrease λ. But, as it was mentioned previously, decreasing of λ is limited by the soil absorption and it should be admitted that under given particular field conditions a void may be not detectable at all.

The above reasons explain why the detection of underground cavities remains fundamentally difficult and why several cases are not solvable. Except some general principles, each case requires a particular study. Indeed, the cases presented in this paper relate such situation where the extremely high absorption limits f_e, even for the relatively small depths.

The presence of voids perturbs the waves propagating downwards and upwards from the markers located beneath. This results i a so called *masking* of the deeper seismic markers. Our experience shows that between different void induced perturbations, masking effect is always dominating (Piwakowski, 2004). This symptom is often followed by the perturbation of the closest upper marker. In order to express the detectability of a void, we have introduced the anomaly coefficient AN (Piwakowski, 2004) defined as $AN = S_c / S_f$ for $S_c \leq S_f$, where S_c is the surface of void and S_f is the Fresnel surface. Our experience (Piwakowski et al., 1997) shows that in order to perform a successful detection, the AN should be greater than 0.35 – 0.5, depending on the site conditions. According to this model, if S_C becomes equal to S_f, (i.e if $AN = 1$) the gallery is sufficiently big and produces the same signal as reflected from a geological layer.

Results

The presented results are related to two HRS experiments carried out on underground marlpit quarries in Haute Normandie. The first survey was carried in 2002 (Driad, 2002) and the second in 2006. The measurements were performed on three sites along six seismic profiles. Acquisition was done using the 48-channel Strata View seismograph and end-off geometry. Table 1 summarizes general parameters of each profile pointing out the void characteristics like its depth and the AN coefficient. Notice that except the profile GR, all voids have sufficient dimensions to expect their detectability. All profiles were carried out using in-hole "buffalo gun" (firing blank cartridges). The profile GO was measured twice:

i. the profile with buffalo source was limited in length due restricted experimental zone,
ii. the new portable P vibrator (*100 kg, 700 W*) and its optimized sweep generation procedure developed in the frame of our research allowed new HRS measurements extend over the restricted zone (i.e. habited zone). This non-destructive source has been used in private ground without any damage or disturbances for the inhabitants.

In order to check the "true" reliability of detection, the survey profiles AA and BB (Eturqueraye site) were conducted without *a priori* knowledge of the void position.

Tab.1 Acquisition geometry and resolution related parameters for sections shown in Figures 1, 2 and 3.

Site	Profile	Source type	Geo-phone type Hz	Geophone spacing/ CDP spacing	Achieved exploited frequency f_e	Exploited wavel-ength λ	Lateral Reso-lution δ_x	AN	Void depth	Position known before the survey
St Gilles	GR	Shotgun	100	1/0.5	90	10	13	0.34	33	Yes
	SGA	Shotgun	100	1/0.5	90	10	13	1	35	Yes
Goderville	GO B	Shotgun	100	1/0.5	100	12	16	1	45	Yes
	GO V	Vibro P	28	1/0.5	100	12	16	1	45	Yes
Eturqueraye	AA	Shotgun	28	3/1.5	30	33	>45	?	>45	No
	BB	Shotgun	28	3	30	33	>45	?	>45	No

Site of St Gilles de la Neuville (Fig.1) The section (a) shows the locations of profiles in relation the positions of voids and the general geological setting. The voids occur at dept of 35 m in chalk layer, covered by alternated chalk and clay.

The profile GR is the reference section situated within the void-free zone and crosses a small tunnel of 7 m width (its *AN*=0.34). The obtained section shows numerous markers: *2, 3,... 7* and it can be observed that the obtained resolution is relatively low (i.e. f_e too low). Notice also the important natural irregularities of the structure. The expected masking caused by the tunnel is practically not seen; indeed, taking into account its *AN* = 0.35 the tunnel is close to the detection limit.

The profile SGA includes the void-free zones (*CMP < 90* and *CMP > 160*) and the zone including the void (*90 < CMP < 160*). The void manifests itself by the following phenomena:

- Within interval *75 < CMP < 120 & 150 < CMP < 185*: perturbations of the marker *3* and nearly total masking of markers *4, 5, 6, 7*.
- Within interval *75 < CMP < 135* we can observe the quite strange seismic behaviour S and diffraction D which might be interpreted respectively as the effect of a local fill of an old subsidence and the presence of filled in well.
- In the contrary the effects seen within interval *150 < CMP < 185* are rather evident. The perturbations of *2* suggest that the void is collapsing there and reaches depth of 25 m

Site of Goderville (Fig.2) This study compares the results obtained with the explosive and vibratory source.

GO-B profile: The presence of the void is clearly seen for *CMP* > 105 by means of the perturbations of upper marker *3* and the masking of deeper markers *4, 5, 6, 7*. The precision of location of the void limit (2.5 m) is much better than expected (δ_x =16m).

GO-V profile .This profile is longer then the profile GO-B since the non-destructive source was used. It reveals the same markers *3* à *7* seen already in GO-B. Notice that the quarry effect is now in the middle part of profile (250 < *CMP* < 330) giving better imaging. The natural geological structure is located symmetrically on its both sides.

Site of Eturqueraye (Fig.3). This study is carried out without a priori knowledge of the marlpit position. The extremely high ground absorption, implied to use a very low fe (such as used in deep seismic!) which resulted in very low resolution seismic image. The proximity of a motorway and of the high voltage power line caused additional difficulties.

The profile AA manifests a masking of marker *2* within the interval *(65 – 115) m.* and less evident perturbations of *1*. Thus this zone is interpreted as the effect of marlpit gallery.

The profile BB indicates the similar results within the interval *(50 – 100) m.* but perturbation of *1* zone is much larger (position of gallery probable but less evident)

The positions of presumed voids are shown in Fig.3.a The found positions agree with the known position of the void given (after interpretation) by the owner of the investigated site.

Conclusions

- The geological structure of investigated sites is irregular and displays numerous natural anomalies. Additionally, the high ground absorption implies the necessity to use low frequencies that lower the resolution. These two factors make the detection of voids relatively difficult.
- Despite the latter limitations (notice the relatively low frequencies on the seismic sections) the voids were however detected. The masking of the deeper markers and perturbations of the upper marker (if close to the void) were the dominant symptoms. The precision of detection is close or even much better than estimated lateral resolution of the survey.
- The comparison of Buffalo and P vibrator sections shows the great utility of the non-destructive P vibrator. The obtained results are quasi identical but the lower-costs survey and non-destructivity are the advantages of vibratory source.

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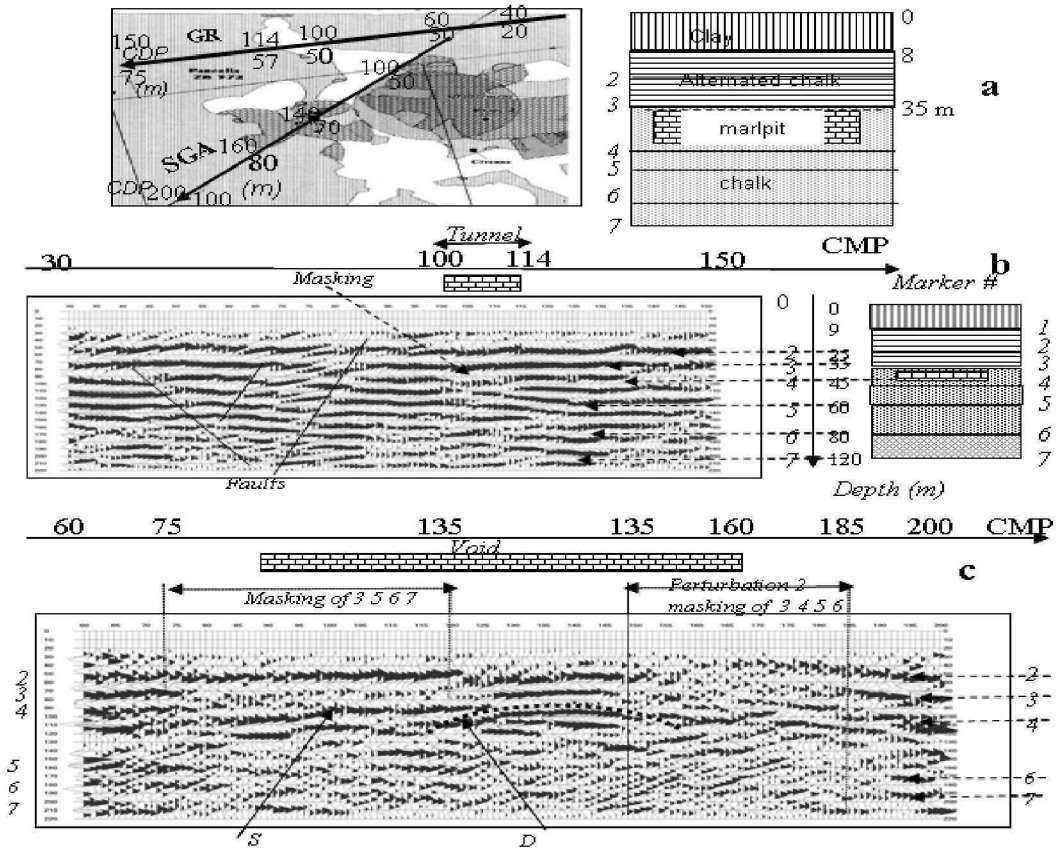


Fig.1.Site of St Gilles **a)** Location of profiles, the void limits and geological structure; **b)** Section GA and interpretation c) Section SGA and interpretation

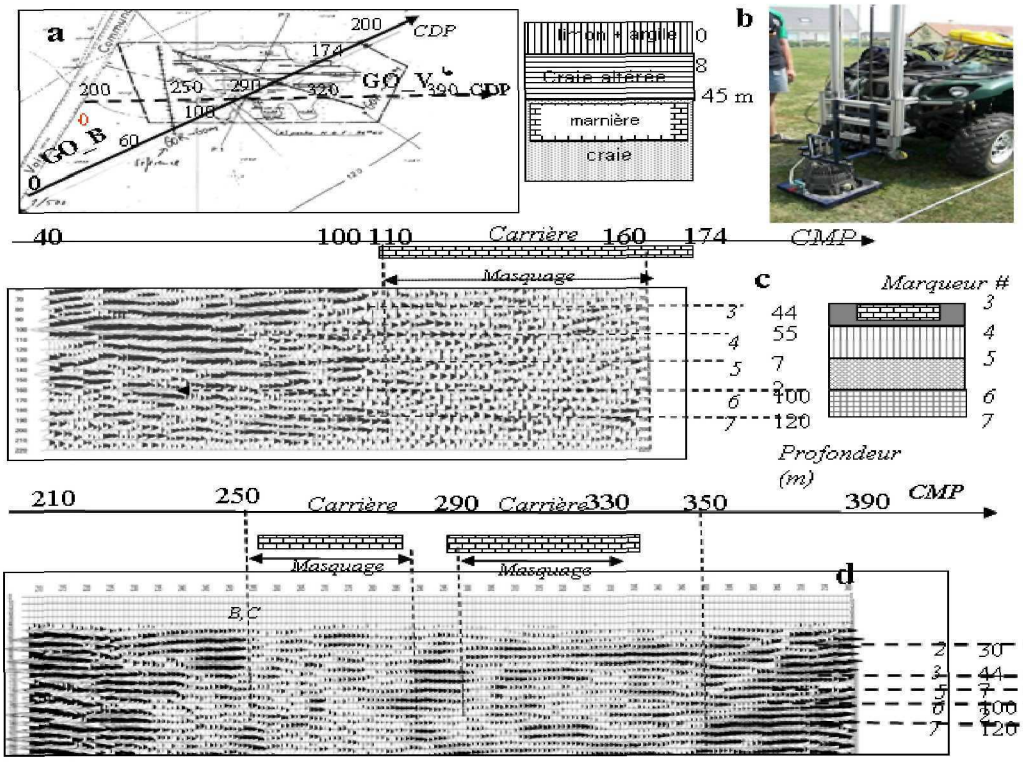


Fig.2.Site of Godedrville **a)** positions of profiles et and void limits; **b)** P vibrator mounted on an all terrain vehicle (quad) **c**) Section GO_B and interpretation **d)** Section GO_V and interpretation.

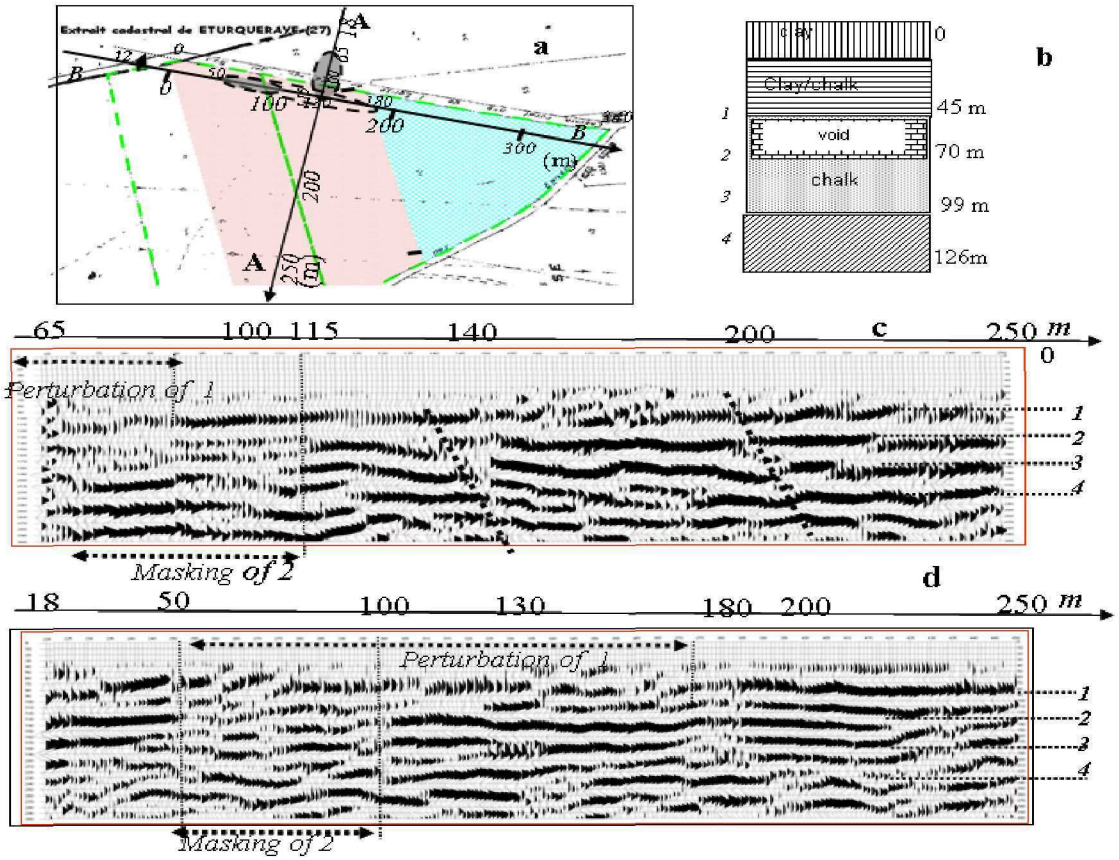


Fig.3.Site of Eturqueraye **a)** Locations of profiles and void limits (perturbations of 2:filled ellipses perturbation of *1* :dotted ellipses);**, b)** geological structure **c)**Profile AA **d**) Profile BB