Long distance propagation of shock waves in the open atmosphere

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1 Context and Objectives

Despite significant progresses in the understanding of the formation and propagation of pressure waves in the open atmosphere in the past decades, experience form past accidents (AZF, Toulouse, 2001, Billy-Berclau, 2003 and even Buncefied 2005) reveals that overpressure levels may be greatly ill estimated. This is obviously a concern when the protection of citizens is concerned.

There are some indications that both the topography and weather conditions may play a significant role but this remains rather qualitative and there is a need to clarify such points. In this paper, the results of a preliminary experimental campaign are presented in which up to 500 kg eq TNT was detonated in the open atmosphere and the pressure field measured up to 10 kms.

2 Existing knowledge

Most traditional models for the propagation of shock waves in the open atmosphere assume an isotropic and homogeneous atmosphere ([1],[2]) but their results may diverge significantly especially when the overpressure is small (Figure 1). When analyzing the damages following an industrial ([3, 4]), it appears that the evolution of the pressure field at large distances seem to be different from the traditional 1/x decay with the distance. In fact (Figure 2), the decrease of the overpressure seems much less especially in the range 0-50 mbar. In practice from one method to the other a ratio of 2 at least are possible especially in the low pressure range (below 100 mbar).

Several reasons may explain these discrepancies. The vertical gradient of the wind may serve as a "wave guide" which may explain the different-from-isotropic propagation of the shock wave [5]. Second, density gradients may also play a role by diffracting the waves by this point does not seem to have been deserved a great attention (Figure 3 from [6]). The topography and the nature of the ground is potentially also of some importance for instance by modifying the frequency spectrum of the wave (low frequency waves are less absorbed by the atmosphere).

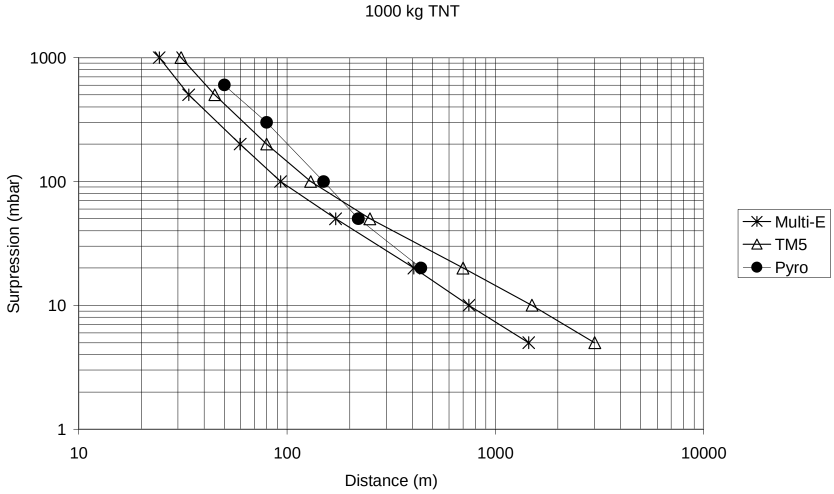


Figure 1 : different models for the spherical propagation of a shock wave produced by detonating 1000 kg TNT. (numeric : Multi-energy method ; experimental : TM5-1300, French regulation).

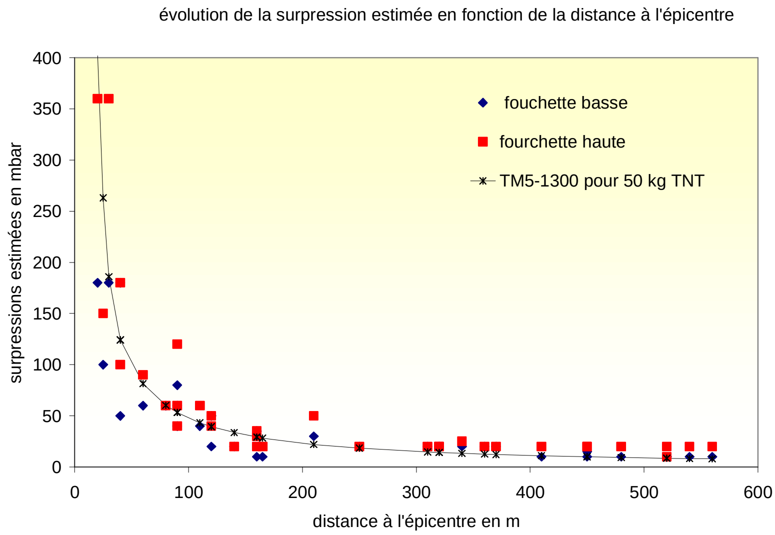


Figure 2 : upper (squares) and lower (diamonds) bounds of the pressure levels (from the damages) as function of the distance after the Billy-Berclau explosion (50 kg of explosive)

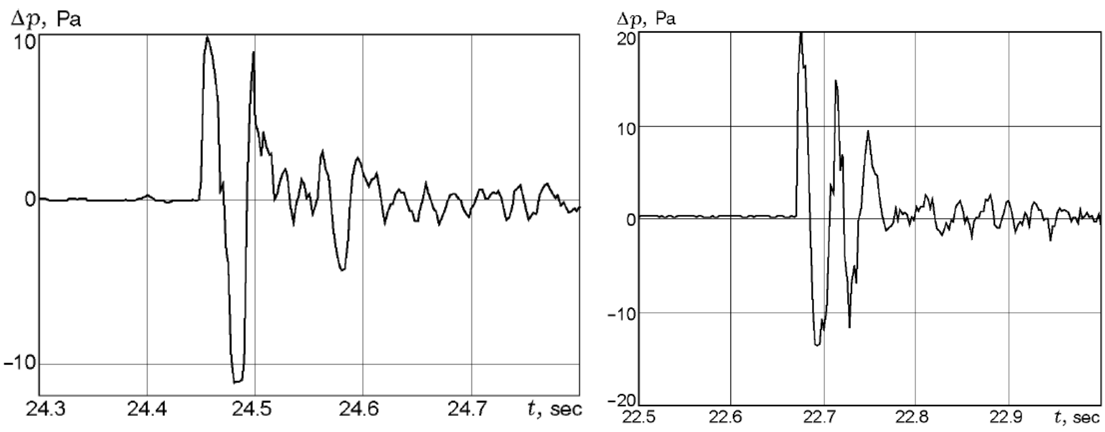


Figure 3 : 1 ton TNT fired in a « stable » atmosphere stable (right) and in the presence of an « inversion layer” (left : nearly no wind). From [6]

3 Experimental site and instrumentation

The experimental site is belonging to Nobelclad Europe and is located in the south of France, near Perpignan. This site is a "pyrotechnical" zone devoted to the everyday activity of the company specialized in the welding of thick metal plates using the heat and pressure of a detonating material (Figure 4). The explosive is a powdered ANFO layered in typical thicknesses of 90 mm. Up to 1000 kg can be detonated corresponding to an energy of about 500 kg TNT [7].

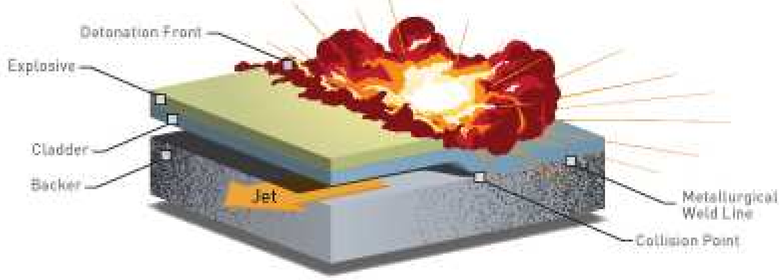


Figure 4: explosive cladding of two metal plates

A view of the experimental site is shown on figure 5. The explosion area is located on a flattened platform at the bottom of a sort of basin 50 m long, 20 m wide. The surrounding hills culminate about 60 m above the platform. A sort of corridor is leaving the platform eastwards and is more or less at the same altitude than the platform.

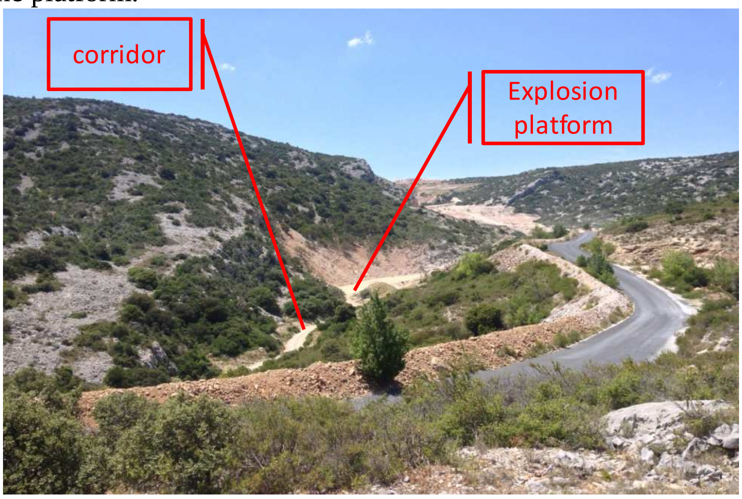


Figure 5 : experimental site

Two traditional pressure sensors (named K1 and K2) were used in the nearfield (Kistler 4043A) and installed so as to measure the incident pressure : the first at about 30 m from the detonation point and the second about 300 m away.

In the far field, 4 microphones (PCB 377B02 3-20000 Hz ±400 Pa) associated to small oscilloscopes and computers were installed up to 10 kms from the explosion platform (at Omya 1400 m, Vingrau 3800 m, Montpins 4200 m and Nobelclad estates 9400 m) along 2 perpendicular directions.

The wind direction, intensity, air humidity and temperature are continuously measured.

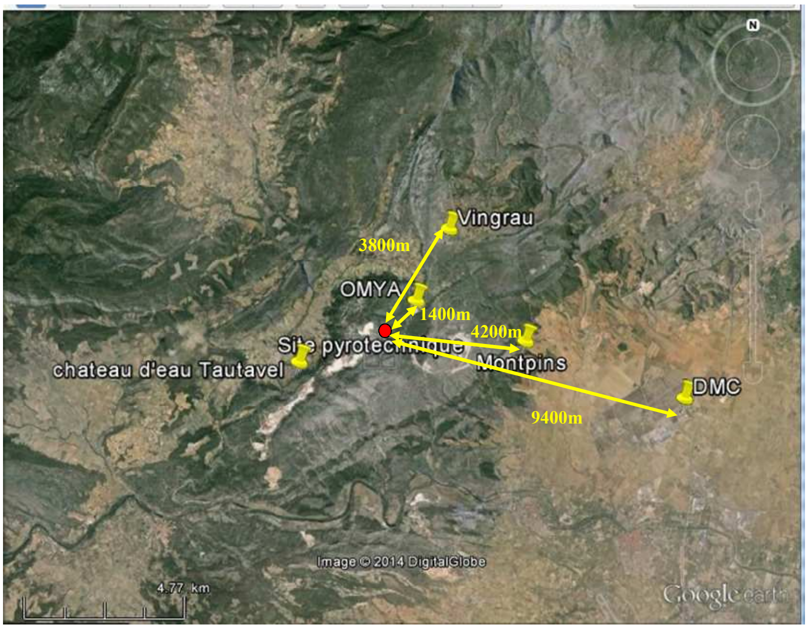
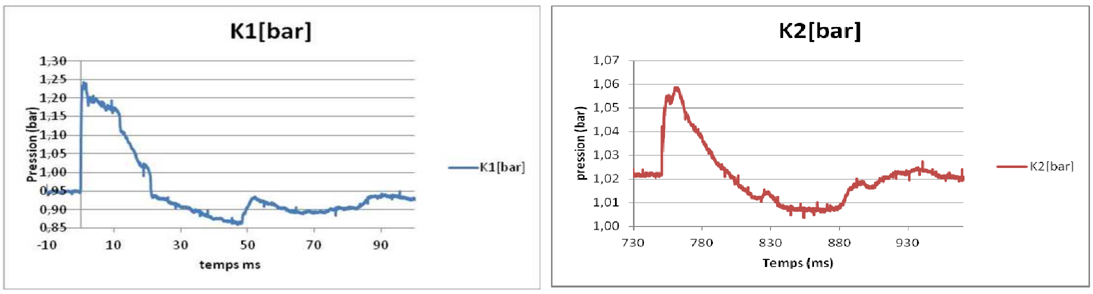


Figure 6 : Far field instrumentation

4 Results

A typical example is presented below corresponding to the detonation of 333 kg of TNT layered over 3 plates (thickness of the ANFO layer=95 mm, test n°00052).

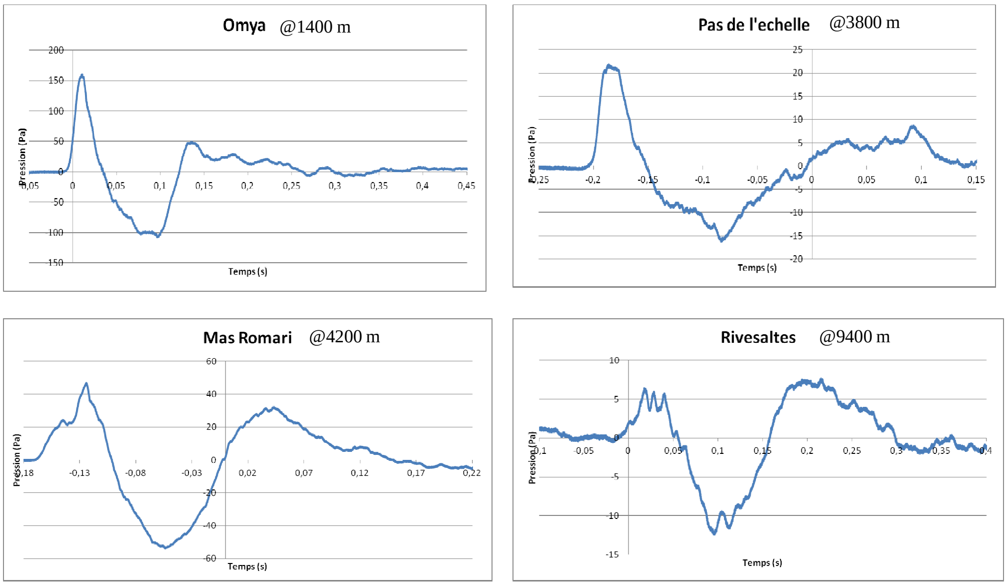
By comparing both the shape of the pressure traces and the characteristic parameters to the theoretical estimations (in figure 7 from []), it is clear that the actual shocks waves are significantly different. The overpressure about 30 m (K1) from the detonation initiation is lower that the theory but the duration and impulse are in line. This suggests that most of the initial energy of the ANFO charge is transferred to the wave. The shape of the wave is not "triangular" suggesting the wave is not totally formed or was modified by the local topography. At larger distance (K2@300 m), the overpressure and impulse are greater than predicted but this may result from the channeling effect of the "corridor".



Sensor	Distance (m)	Measurements			Predictions [5]		
		Overpressure (bar)	Positive duration (ms)	Impulse (Pa.s)	Overpressure (bar)	Positive duration (ms)	Impulse (Pa.s)
K1	30	0.3	22	350	0.5	24	300
K2	300	0.035	50	100	0.02	50	30

Figure 7 : overpressures measured in the near field (330 kg TNT, test n° 00052)

Very far from the explosion platform (figure 8), the shape of the waves is not any more a shock. The initial shock wave has lost the high frequency portions (max frequency at 1400 m is about 100 Hz), presumably absorbed by the air humidity [9]. Note that the rarefaction wave following the initial shock and the subsequent “vibrations”/echoes do not attenuate as rapidly. There is apparently a significant directional effect (compare 3800 and 4200 m) although there was nearly no wind during the test. Lastly, the maximum overpressure seems to be much below the acoustic approximation [8].



Sensor	Distance (m)	Measurements			Predictions [8]
		Overpressure (Pa)	Positive duration (ms)	Impulse (Pa.s)	Overpressure (Pa)
Omya	1400	160	45	7	600
Vingrau	3800	22	50	1	200
Montpins	4200	45	70	3	150
Rivesaltes	9400	7	60	0.2	70

Figure 8 : overpressures measured in the far field (330 kg TNT; test n° 00052)

Some evolutions of the overpressures as function of the explosive charge are presented on figures 9 (near field) and 10 (far field). A considerable scattering of the results is seen which is greater, the larger the distance. From the available data, correlating the far field overpressure measurements to the global weather parameters does not provide any clear relationship.

4 Conclusions

In this work, an effort is made to clarify the environmental parameters on the propagation of pressure waves at larges distances (kms). Experiments are currently being performed on a pyrotechnical site detonating hundreds of kgs of ANFO. Preliminary results are presented but more data will be issued shortly.

Present information reveals a very large scattering of the data and that the theoretical models are not in line with the measurements.

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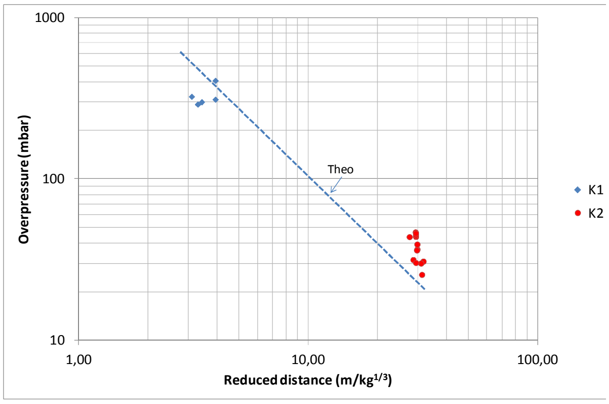

Figure 9 : nearfield overpressures as function of the reduced distance

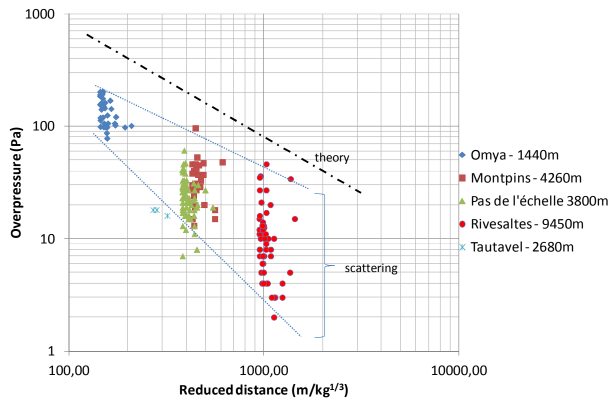

Figure 10 : farfield overpressures as function of the reduced distance

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