BARRICADE INFLUENCE ON BLAST WAVE PROPAGATION

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ABSTRACT

As everyone knows, barricade is one of the most efficient means available to protect persons, goods and facilities againts fragments. It is also an efficient solution to minimize blast hazards by reducing overpressure level just behind.

Purpose of this study is to check that there is effectively an overpressure decrease behind barricade and to assess it.

In order to improve our knowledge on this phenomenon, we analysed scale model tests performed at Captieux (south of France). These tests consisted in overpressure measurements in free field and behind barricades to compare them. During these tests a double barricade efficiency was also assessed.

Simultaneously, numerical simulations were carried out with a two dimensional finite volume code based on Euler equations. Following parameters were used in this study :

NEQ (Net Explosive Quantity),
Shape and sizes of barricade,
Scaled distance between charge and barricade.

Computed and experimental results are in a good agreement.

1 - INTRODUCTION

NATO AC 258 [1] has introduced a few years ago "Quantity Distance" notion to ensure the minimum practicable risk to life and property. French Regulation [2] kept also this concept by defining five hazardous areas depending on level of potential damages on personal and property :

Report Documentation Page	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE **AUG 1994**	2. REPORT TYPE	3. DATES COVERED **00-00-1994 to 00-00-1994**

4. TITLE AND SUBTITLE **Barricade Influence on Blast Wave Propagation**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **SNPE/Division Defense Espace,Centre de Recherches du Bouchet,91 710 Vert le Petit,France,**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

See also ADM000767. Proceedings of the Twenty-Sixth DoD Explosives Safety Seminar Held in Miami, FL on 16-18 August 1994.

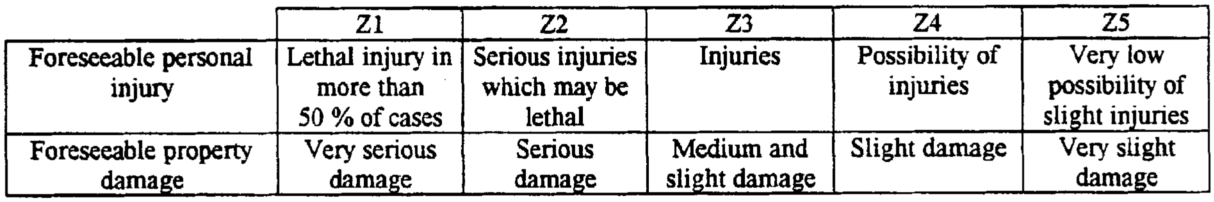
14. ABSTRACT

see report

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**13**	

TABLE 1: Hazardous areas definition



	Z1	Z2	Z3	Z4	Z5
Foreseeable personal injury	Lethal injury in more than 50 % of cases	Serious injuries which may be lethal	Injuries	Possibility of injuries	Very low possibility of slight injuries
Foreseeable property damage	Very serious damage	Serious damage	Medium and slight damage	Slight damage	Very slight damage

Table 1 : Hazardous areas definition

As we can notice on this table, definitions are rather qualitative than quantitative. However, hazardous areas limits are determined with simple formula. For example, for 1.1. hazard division products (mass exploding) radius of circular concentric zone is given by :

$R = k\,Q^{1/3}$ with

k : coefficient depending on zone to be considered (m/kg1/3)
Q : net explosive quantity (kg)
R : radius of zone (m)

Charge is supposed to be on the floor, in free field.

More precisely, we have fhe following relationships :

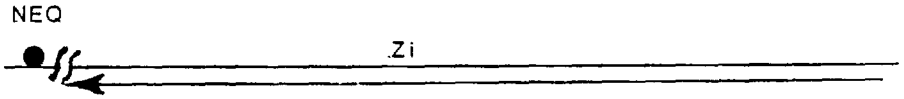
- $R1 = 5\,Q^{1/3}$
- $R2 = 8\,Q^{1/3}$
- $R3 = 15\,Q^{1/3}$
- $R4 = 22\,Q^{1/3}$
- $R5 = 44\,Q^{1/3}$

2 - THE NEED

First function of a barricade is to protect personal, and goods againts projections. But in the case of bare charge detonation (no fragments emitted) french regulation admits that it also minimizes danger by reducing overpressure level. Main consequence on hazardous area is as follows :

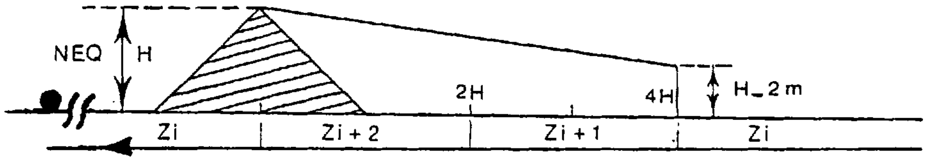
ž Suppose that there is a charge in free field. Let us consider that we are in Zi hazardous area.

Figure 1A.



- Suppose now that there is a barricade near by the charge also included in Zi. Then,

Figure 1B.



When this law is applied, barricade is assumed to remain intact (it is not fractured). In this study, purpose is to assess overpressure decrease behind barricade by making to vary net explosive quantity and/or distance from the charge to the barricade. We want, in particular, to be able to answer at two questions :

- What is the influence of standoff distance between charge and barricade on overpressure decrease ?

- Although we thought that a double barricade (consisting in two consecutive barricades separated with a very short distance) is more efficient than a single, is the difference significantly important ?

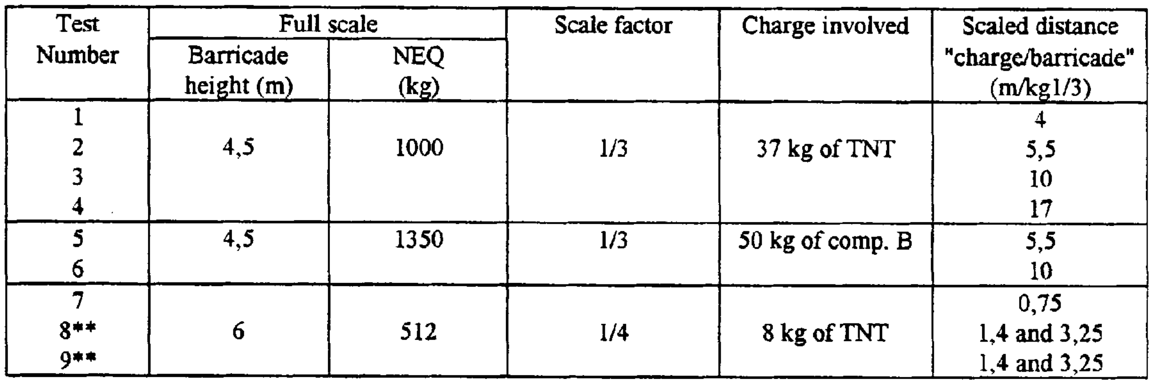
In order to improve our knowledge on interaction between blast wave and barricade, scale model tests were performed in our full scale tests facilities (at Captieux in south of France) and analysed. These tests gave us opportunity to check our predictive tool on shock wave propagation in the air. It is the reason why numerical simulations were carried out with a two dimensional finite volume code based on Euler equations.

3 - SCALE MODEL TESTS [3]

3.1. Trials features

In 1988, scale model tests were performed at Captieux to measure overpressure behind barricade and in open field. Table 2 summarizes features of each test.

Table 2. Test data



Test Number	Full scale		Scale factor	Charge involved	Scaled distance "charge/barricade" (m/kg1/3)
	Barricade height (m)	NEQ (kg)			
1 2 3 4	4,5	1000	1/3	37 kg of TNT	4 5,5 10 17
5 6	4,5	1350	1/3	50 kg of comp. B	5,5 10
7 8** 9**	6	512	1/4	8 kg of TNT	0,75 1,4 and 3,25 1,4 and 3,25

** double barricade

Table 2 : Test data

Only one type of barricade was taken into account for these scale model tests. Its main features are :

- 1,5 m high
- mixture of wet sand and earth
- triangular section
- 45° sloping

According to scale factor (1/3 or 1/4), it corresponds to either 4.5 m or 6 m full scale height barricade .

As it is pointed out in table 2 three kinds of charge were used :

- 8 kg of TNT charge, box shaped
- 37 kg of TNT charge, box shaped
- 50 kg of Comp. B hemispherical charge

These charges laid down on two superposed steel slabs (0.05 x 1 x 1 m3) which were on the floor to produce a "perfect" reflected shock wave. During these tests, overpressure measurements were led in free field and behind barricade. At this occasion, two types of overpressure gage support were tested according to overpressure level that we expected to record and blast wave propagation direction (supposed to be complex behind barricade) :

- horizontal streamlined rod for incident overpressure measurements in free field at about 2 m off ground,

- lentil

(diameter ϕ = 50 mm, thickness t = 5 mm).

These were designed for measuring incident overpressure from wave which propagation direction is well defined but incident angle unknown. Two heights were considered : 0.35 m and 0.75 m off ground. These were used for overpressure measurements just behind barricade.

The following diagram shows overpressure gage locations on both sides of barricade.

Figure 2 : Overpressure gage locations

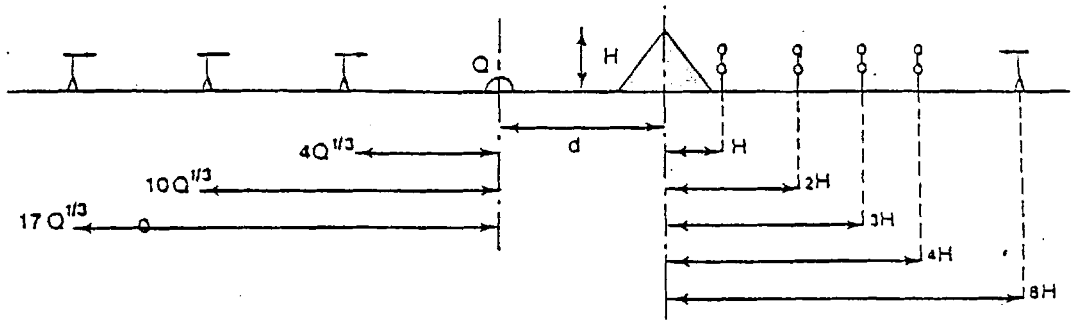


Figure 2 : Overpressure gage locations

Behind barricade, four vertical reeds were placed at 1H, 2H, 3H and 4 H away from top of barricade (H is the height of barricade), each with two overpressure gages at 0.35 m and 0.75 m off ground. Another gage is placed at 8 H to know if shock wave is always pertubed far from barricade. On the other side, in free field, three gages were placed at 4 $Q^{1/3}$, 10 $Q^{1/3}$ and 17 $Q^{1/3}$ from the charge (Q is the net explosive quantity).

3.2. Results

Generally, recorded overpressure behind barricade consisted in one high intensity peak which was representative of incident overpressure. However, in some cases, two peaks were observed, one, high intensity well defined corresponding to incident overpressure and the other one, low intensity smoothed coming from reflected parasite shock wave. For this study, only incident overpressure was taken into account.

The results are presented in the form of curves describing maximal recorded overpressure variation behind barricade and in free field. Barricade is assumed to be placed at the origin of diagram. We recognize 1H, 2H, 3H, 4H and 8H distances mentioned above. Black continuous line corresponds to overpressure in free field, and dotted line to overpressure behind barricade. Thus, a direct comparison is possible between both measurements. For each case, distance between charge and barricade is written down in the middle of each diagram (for example, 4 $Q^{1/3}$, 5.5 $Q^{1/3}$, 10 $Q^{1/3}$, and 17 $Q^{1/3}$ for 37 kg of TNT). Figures 3 and 4 hereafter, present all experimental results that we get during these tests.

Figure 3

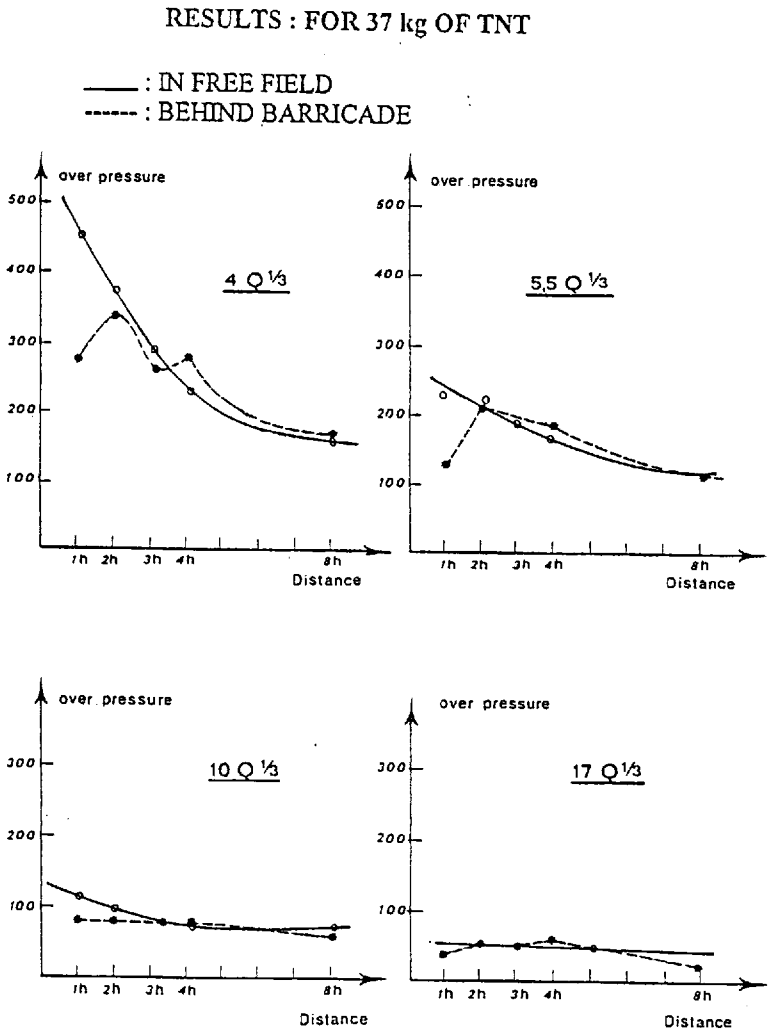


Figure 3

Figure 4

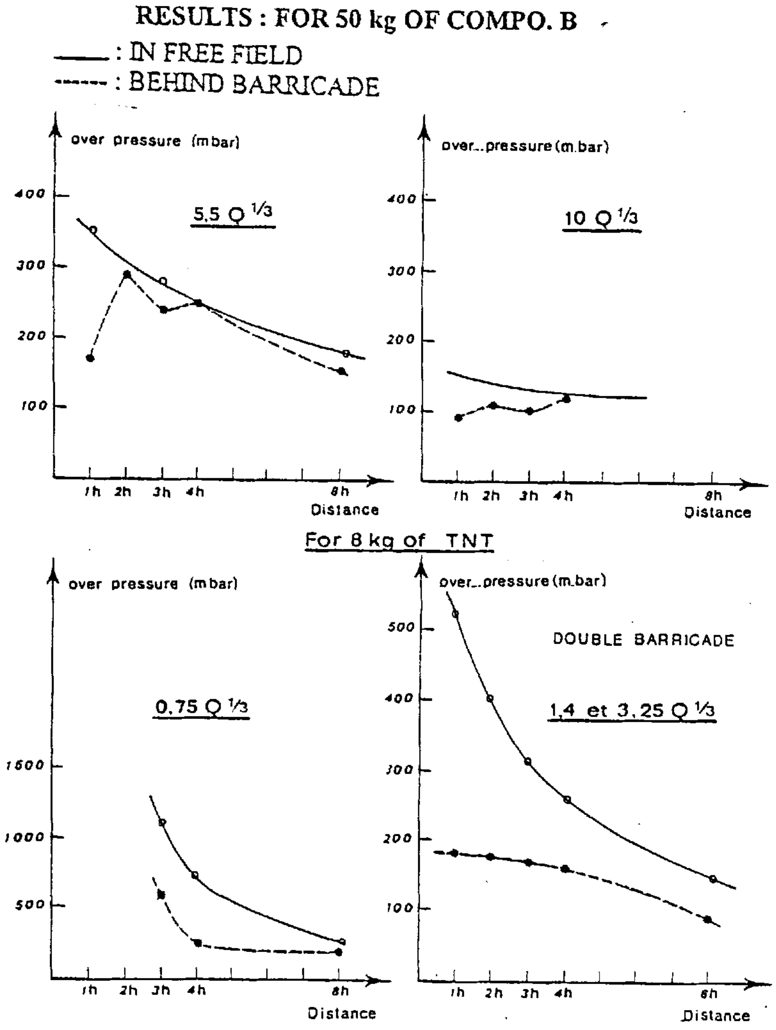


Figure 4

It is obvious that the different lines which bind experimental points on previous diagrams have not any physical meaning. They only exist to clarify presentation in order to make as easely as possible a quick comparison.

After looking at these diagrams, following remarks can be made:

- Concerning scale model tests involving 37 kg of TNT, for any "barricade-charge" distances that we consider (4 $Q^{1/3}$, 5.5 $Q^{1/3}$, 10 $Q^{1/3}$ or 17 $Q^{1/3}$) we notice a big decrease of overpressure up to 1 H distance behind barricade

EQUATION

$\left(\frac{\Delta P}{P} \approx 35\ \%\right.$ with P : overpressure in free field - ΔP : difference of overpressure in free field and behind barricade).

Beyond this limit, shock waves spread like in free field.

ž   This remark can also be applied to overpressure measurements performed for test involving 50 kg of comp. B : decrease was important up to 1 H behind barricade. Beyond 1 H difference becomes negligible.

ž   In the case of a charge (8 kg of TNT) placed beside barricade, effects on overpressure are very important (difference may reach 50 %) and seem extended to 4 H.

ž   The case of double barricade is the most efficient (it is recalled that the first and second barricade are respectively 1.4 $Q^{1/3}$ and 3.35 $Q^{1/3}$ away from 8 kg TNT charge). Up to 4 H behind barricade, overpressure decrease varies from 40 % to 70 %.

4 - NUMERICAL SIMULATIONS 3

4.1. Principle

Model that we used to determine overpressure decrease behind barricade is based on Euler equations. It is a two dimensional finite volume code, called PATRIC. Overpressure decrease assessment in free field were performed with a 1D model by keeping same assumptions. In a word, principle of calculation consists in solving Euler equations :

EQUATIONS

$$\frac{\partial U}{\partial t} + \frac{\partial F}{\partial x} + \frac{\partial G}{\partial y} = 0$$

with

$$U = \begin{pmatrix} \rho \\ \rho u \\ \rho v \\ \rho E \end{pmatrix} \qquad G = G(u) = \begin{pmatrix} \rho v \\ \rho uv \\ P + \rho v^2 \\ (P + \rho E)v \end{pmatrix}$$

$$F = F(u) = \begin{pmatrix} \rho u \\ P + \rho u^2 \\ \rho uv \\ (P + \rho E)u \end{pmatrix}$$

(u, v : velocity components - ρ : density - P : pressure - E : energy)

Equation of state is in the following form:

EQUATION

$$P = (\gamma - 1)\rho\left(E - \frac{u^2 + v^2}{2}\right)$$

Where γ is isentropical coefficient.

At first, right initial parameters (detonation pressure, velocity, temperature and so on) of explosive charge detonation are chosen or assessed. Thus, model calculates parameters variation versus time and plan location.

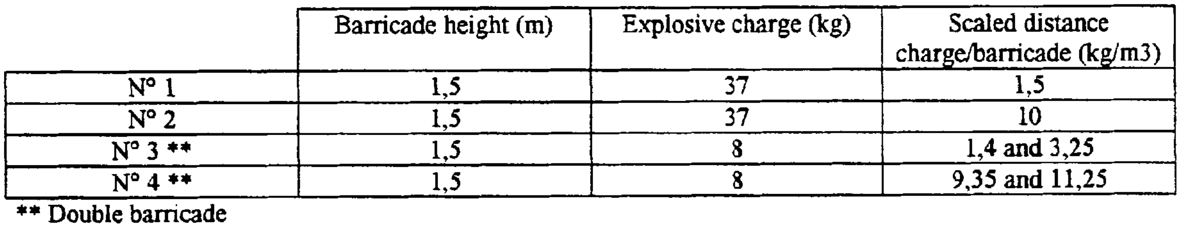
4.2. Computed cases

Two main reasons guided us for choosing configurations to be computed :

- to study maximum number of different situations : single or double barricade, near or away from the charge,
- to keep conditions (Net Explosive Quantity, distance, barricade sizes, ...) of some scale model tests performed earlier.

So, four cases were considered :

TABLE 3: Computed cases



	Barricade height (m)	Explosive charge (kg)	Scaled distance charge/barricade (kg/m3)
N° 1	1,5	37	1,5
N° 2	1,5	37	10
N° 3 **	1,5	8	1,4 and 3,25
N° 4 **	1,5	8	9,35 and 11,25

** Double barricade

Table 3 : Computed cases

Explosive material is TNT. Charge lays down on the floor. Barricade is 45° sloping with a triangular section. It is supposed to reflect perfectly shock wave. What is of a big interest for us, is not to know as precisely as possible TNT overpressure decrease in free field, but to assess difference between overpressure levels in free field and behind barricade. It is the reason why that we do not attempt to fit our simulations in free field to experimental results that we get earlier.

4.3. Results

We kept the same presentation (see figure 5).

Figure 5

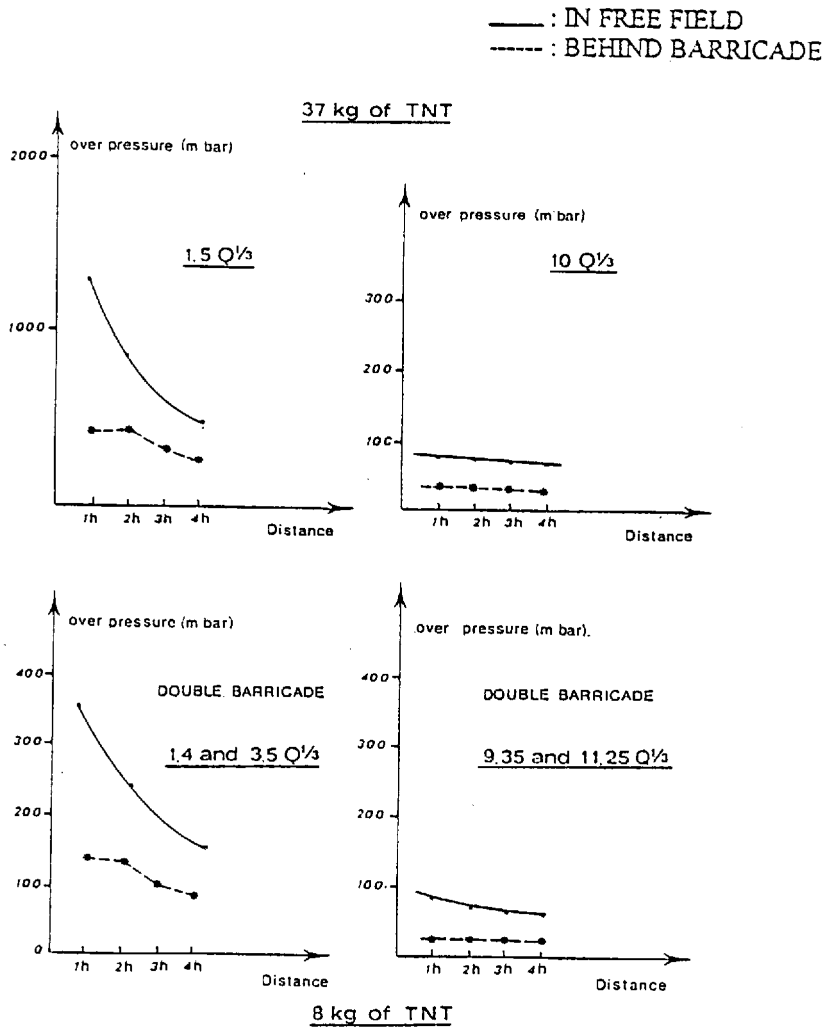


Figure 5

Main comments that we can make after analysing these results are :

ž when charge is close by barricade (1.5 $Q^{1/3}$), we have the confirmation of the great efficiency of barricade :

EQUATIONS

- at 1 H $\frac{\Delta P}{P} = 66\ \%$
- at 2 H $\frac{\Delta P}{P} = 50\ \%$
- at 3 H $\frac{\Delta P}{P} = 43\ \%$
- at 4 H $\frac{\Delta P}{P} = 40\ \%$

ž Concerning double barricade close by the charge (1.4 $Q^{1/3}$ and 3.5 $Q^{1/3}$) we observe roughly the same decreases than these mentioned on previous paragraph. But we can not conclude that a single and a double barricade have the same efficiency in regard with overpressure decrease. In matter of fact, measurements points are more distant in the case of double barricade than these for single barricade.

ž In account of too rough mesh for great distances (10 $Q^{1/3}$, 9.35 and 11.25 $Q^{1/3}$) results seem a little wrong. In matter of fact, according to modelings, barricade might reduce three times overpressure level. Now, all experimental measurements are coherent and point out that barricade (single or double), when situated away from charge, had not any influence on overpressure decrease.

5 - CONCLUSIONS

ž In this study, barricade is much more efficient when it is close by the charge. Overpressure decrease may reach 60-70 % and is extended, at least, up to 8 H behind barricade.

ž On the contrary, when it is away from the charge its influence is negligible. We may notice a slight decrease up to 1 H.

ž   We have checked that a double barricade is more efficient than a single barricade. However difference remains smaller than expected.

ž   Experimental results are in a good agreement with simulations in the cases of short distances between charge and barricade. For great distances, simulations are not satisfactory because of a too rough mesh. But with more available time, our predictive tools could perform more farthermost calculations by using smaller cells and so become satisfactory in any situation that we want to treat.

ž   On the whole, French Regulation was right in admitting that barricade could reduce hazards in regard with blast effect. It is fully true when charge is close by barricade and less obvious when it is away from barricade.

ž   The last remark that we can make is to point out that all the results or comments enclosed in this document are only valid within the framework of this study and not outside. In matter of fact, for example,all what is happening when shock wave passes round a triangular section barricade is not necessary true with a square section barricade. Slope and height of barricade, distance beetween charge and barricade, barricade and soil material, ... are parameters which have each one a great influence on overpressure propagation. So, beware of any extrapolation!

This work can be considered like a begining. Every change of parameters values in regard with this study shall require an additional technical study.

REFERENCES

1 NATO AC/258 - D/425 (AASTP-1) - May 1992

2 Sécurité pyrotechnique - Décret n° 79-846 - 28 september 1979

3 Private communications