ATTENUATION OF THE DESTRUCTIVE EFFECTS OF AN EXPLOSION BY STRATIFIED SCREENS

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ABSTRACT

The demolition of the buildings with explosives presents a series of risks for the environment and for the persons within the incidence of the explosion effects. The putting into practice of an explosion demolition work, in particular in the urban environment, means also a compromise between the quantity of explosive used/ its disposal for achieving the desired purpose and the protection effective level of the environment/ of the persons within the incidence of the explosions. The practice in the field proved that this compromise could be realized concomitantly, by the use of explosive charges resulted from calculations as being necessary for the realization of the desired effects, with the execution of explosion simulations of these charges using protection means accordingly sized so as to reach the safety level required.

Key words: simulation, experiment, explosive charge, ballistic protection means

ABSTRACT

Demolarea clădirilor cu explozivi prezintă o serie de riscuri pentru mediu şi pentru persoanele aflate sub incidenţa efectelor exploziei. Punerea în practică a unei lucrări de demolare prin explozie, în special în mediul urban, înseamnă, de asemenea, un compromis între cantitatea de exploziv folosită / dispunerea lui pentru scopul dorit şi nivelul efectiv de protecţie al mediului / al persoanelor aflate sub incidenţa exploziilor. Practica în domeniu a dovedit că acest compromis ar putea fi realizat concomitent, prin utilizarea de încărcări explozive rezultate din calcul ca fiind necesare pentru realizarea efectelor dorite, cu execuţia de simulări de explozii ale acestor încărcări utilizând mijloace de protecţie dimensionate corespunzător, astfel încât să fie atins nivelul de siguranţă necesar.

Cuvinte cheie: simulare, experiment, încărcări explozibile, mijloace de protecţie balistică

1. INTRODUCTION

The execution of demolition works in the construction field needs to take certain protection measures for the environment, due to the destructive effects manifested mainly as shock waves and the projection of fragments and splinters resulted from the detonation of the explosive charges placed inside the construction elements. These measures consist in the use of ballistic protection means (screens) which may be made of different materials interposed between the explosive charge and the area to be protected.

This paper aims at contributing, on a theoretical and experimental path, in improving the realization of ballistic protection stratified screens, against explosions.

2. THEORETICAL STUDY OF ATTENUATION OF EXPLOSIONS' EFFECTS BY STRATIFIED SCREENS

In order to optimize the constructive characteristics of a ballistic protection screen, constituted of stratified materials against the explosion's effects, a simulation was made for the attenuation of the explosion pressure of such a screen following the detonation of a concentrated explosive charge of 10 kg TNT. In this purpose, the calculation software with finite elements ANSYS AUTODYN (3) was used to determine the variation of the overpressure in the shock wave front, in two work versions.

Version 1: the simulation of the detonation of a 10 kg TNT charge, placed on the ground, at 2m and 4m respectively from two pressure transducers disposed on the ground, on the same axis with the explosive charge.

Version 2: the detonation of a 10 kg TNT charge, placed on the ground, at 2m and 4m respectively from two pressure transducers disposed on the ground, on different axes with explosive charge, with the difference that a triple-pluristratified screen was disposed between the two transducers, 0,30m thick and 1 m high.

Work method

For the material TNT (trinitrotoluene) the software AUTODYN uses both Lee-Tarver equation of state in order to mold the explosive's detonation and "Jones - Wilkins - Lee" (JWL) equation in order to mold the explosive in its initial state (non-initiated). This material has defined the properties presented in Table 1.

Table 1. *The properties of TNT material*

The equation of state	JWL
The reference density	ρ = 1,63 g/cm^3
The constants	C_1 = 3,7377*10^8 kPa
	C_2 = 3,7471*10^6 kPa
	r_1 = 4,15
	r_2 = 0,9
	ω = 0,35
The speed of detonation	C-J = 6,93*10^3 m/s
The energy	C-J = 6,0*10^6 KJ/m^3
The pressure	C-J = 2,1*10^7 kPa

JWL equation of state can also be written as below (1):

$$p = C_1\left(1-\frac{\omega}{r_1 v}\right)e^{-r_1 v} + C_2\left(1-\frac{\omega}{r_2 v}\right)e^{-r_2 v} + \frac{\omega e}{v} \quad (1)$$

where: p is the hydrostatic pressure, v = 1/ρ represents the specific volume, ρ is the density and C_1, r_1, C_2, r_2 and ω (adiabatic constant) are experimentally determined constants which depend on the explosive's type.

The one-dimensional numerical model, with "wedge" type pre-defined geometry, of a spherical explosive charge in open space is presented in Figure 1.

The initial condition was defined first, the air internal energy should have the value of 2,068x10^5 J, for the air to be at the atmospheric pressure (P = 1 bar).

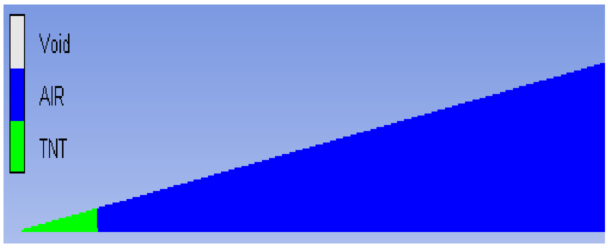

Fig. 1. One-dimensional numerical model

The model was realized with the "Euler multi-material" solver, specific to problems where the gases, fluids or solids which will suffer big deformations will be molded. Having as main advantage the fact that, during the simulation, the elements of the discretized field are not distorted, without the need of rediscretization, the Euler solver is recommended for the molding of shock waves generated on the detonation of an explosive.

Thus, a 4500 mm field was defined, applying, at the same time, the initial condition previously established (P = 1 bar). 450 elements resulted from the discretization process.

The quantity of TNT explosive, weighing 10 kg, was molded under a spherical shape, having the detonation point established in the center of the sphere.

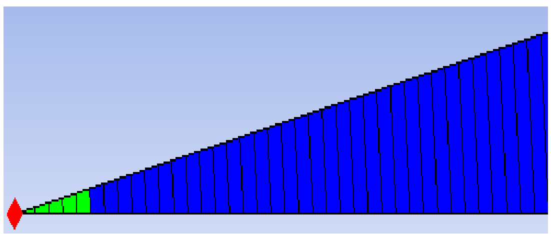

Fig. 2. Numerical model discretization detail

In order to visualize, after the simulation, the overpressure values at different distances from the explosive charge, a series of gauges (elements which have the pressure transducers as physical correspondents) were defined from the modeling phase.

It is known that, by the mathematic processing of certain experimental results, it was proved that the overpressure within the shock wave front, Δp_f, is calculated with the relation (2):

$$\Delta p_f = \frac{808\left[1+\left(\frac{Z}{4,5}\right)^2\right]Pa}{\sqrt{1+\left(\frac{Z}{0,048}\right)^2}\sqrt{1+\left(\frac{Z}{0,32}\right)^2}\sqrt{1+\left(\frac{Z}{1,35}\right)^2}} \qquad (2)$$

where: Δp_f is overpressure in the shock wave front [bar], Pa is air pressure at the moment of detonation [bar] and Z is scaled distance [m].

The scaled distance is determined with the following formula (3):

$$Z = \frac{R}{W^{1/3}} \qquad (3)$$

where: W is the equivalent in TNT of the explosive quantity used [Kg] and R is the distance separating the explosive disposal place and the considered objective [m].

The following two versions present the variation of the overpressure Δp_f with the distance R, being represented, on one hand, based on empirical data, obtained from the equation (3), and, on the other hand, based on the results of the numerical simulations with the AUTODYN software (4).

Version 1: The simulation of the explosion on the ground of a 10 kg TNT concentrated charge, disposed at 2m and 4m respectively away from two pressure transducers.

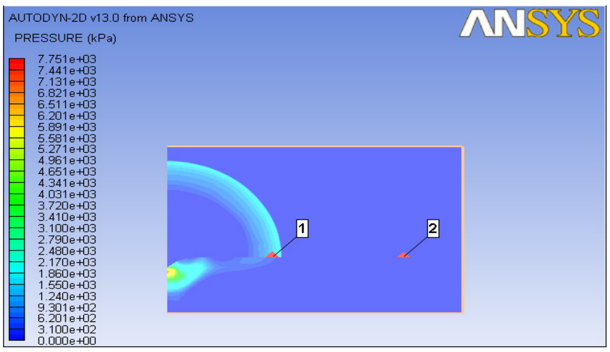

Fig. 3. The simulation of the interaction of overpressure of the shock wave front with the pressure transducer 1

Interpretation of simulations

The pressures measured by the two pressure transducers disposed on the ground, at the distances of 2m and 4,3 m respectively from the explosion, on the ground, of 10 kg TNT, have the approximate values of 18 and 2,4 bar respectively (fig. 3,4,5,6).

Version 2: The simulation of the explosion on the ground of a 10 kg TNT concentrated charge disposed at 2,0 m from a triple pluristratified screen, 1 m high and 0,30 m thick.

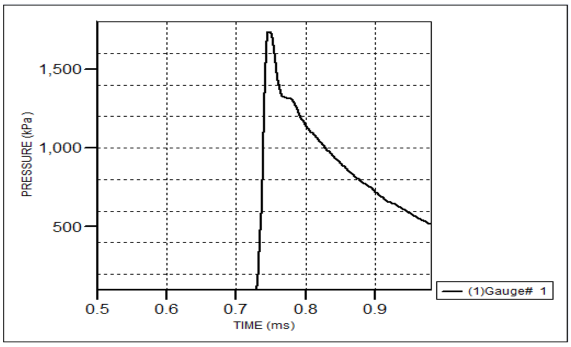

Fig. 4. The measured value of the overpressure of the shock wave front by the transducer 1

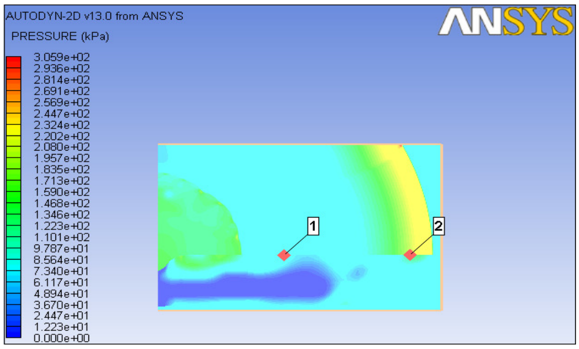

Fig. 5. The simulation of the interaction of overpressure of the shock wave front with the pressure transducer 2

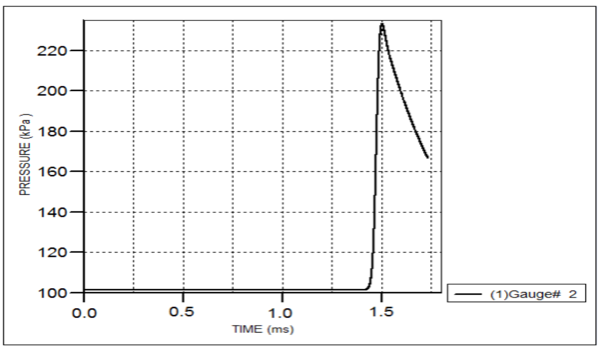

Fig. 6. The measured value of the overpressure of the shock wave front by the transducer 2

Interpretation of simulations

The measured pressured of the two pressure transducers disposed on the ground, at 2 m and 4,3 m respectively from the explosion on the ground of 10 kg TNT (fig. 9), have the values of 38 bars and 80 mbar respectively (fig. 8,10).

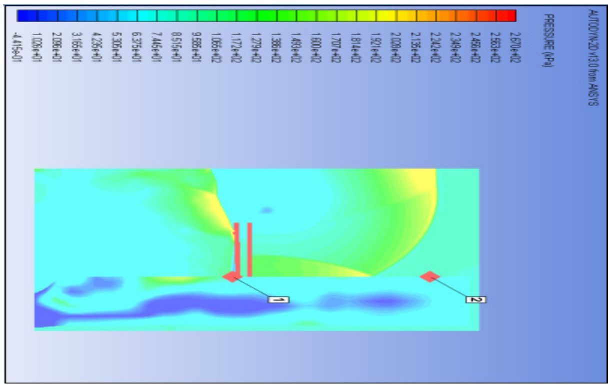

Fig. 7. The measured value of the overpressure of the shock wave front with the triple pluristratified screen

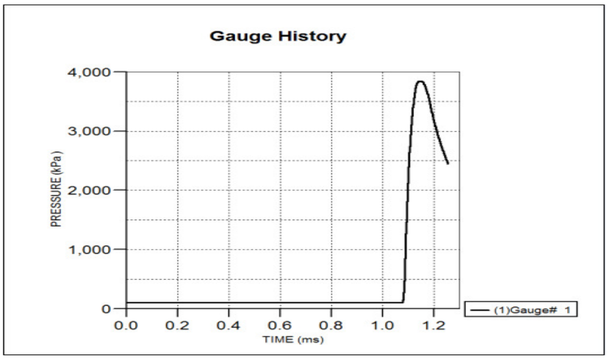

Fig. 8. The measured value of the overpressure of the shock wave front in front of the screen, at its base

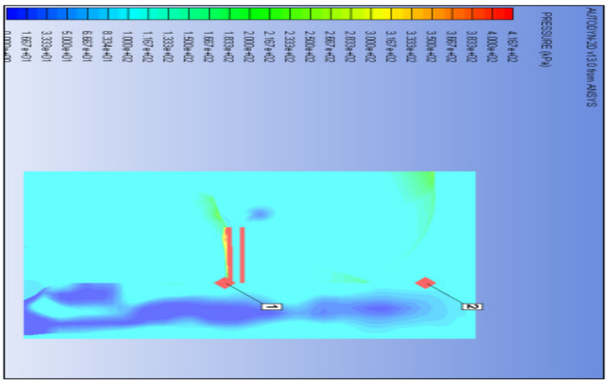

Fig. 9. The simulation of the interaction of overpressure of the shock wave front with the pressure transducer 2

Due to the reflections and refractions of the shock wave overpressure, at the base of the screen the pressure is amplified from the value of 18 bars (fig. 4), corresponding to the version without a screen (fig. 3), to 38 bars (fig. 8). for the screen version (fig. 7). At 2 m behind the screen, the pressure is attenuated from the value of 2,4 bars (fig. 6), corresponding to the version without a screen (fig. 5), to 80 mbar (fig. 10) for the screen version (fig. 9).

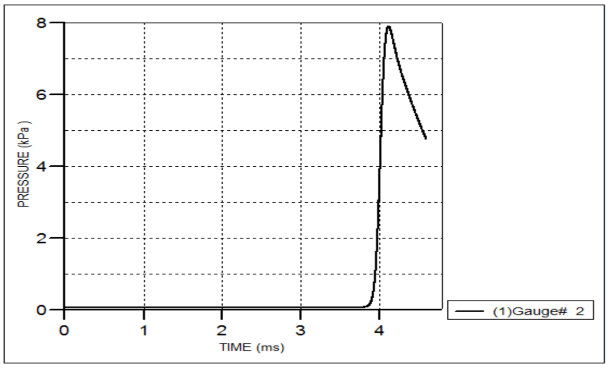

Fig. 10. The measured value of the overpressure of the shock wave front by the transducer 2

3. EXPERIMENTAL STUDY OF THE ATTENUATION OF THE EXPLOSIONS EFFECTS BY STRATIFIED SCREENS

For the validation of the theoretical study of the attenuation of the explosions' effects over the environment by stratified screens, a comparison of the results obtained following the molding and simulation of the detonation of an explosive charge in an open space by the AUTODYN software to the results of experimental tests is imposed. In this sense, an experimental study was performed, which had in view the fulfillment of the following targets:

- the validation of the theoretical study of the attenuation of the explosions' effects over the environment by stratified screens;
- the study of behavior to the explosion's action of the stratified screens disposed as to the explosive charge, at a smaller distance than the radius of the explosion's total destruction area (R = Q/2, where Q is the

weight of the explosive charge in TNT equivalent);

- the determination of the efficiency of the environment's protection level on a direction established against the explosion's bursting effect (blow and splinter effect), by stratified screens;
- the study of the phenomenon of shock wave attenuation by stratified screens;
- the evaluation, depending on the results obtained, of the possibilities to use the stratified screens in the protection of certain areas/ buildings/ people, from the explosion's destructive effects.

3.1. The conditions of the experiment's execution

For the fulfillment of the proposed objectives, 4 fiber glass screens were built at S.C. STIMPEX S.A. Bucureşti, with the dimensions of 100 x 50 x 27 cm each, provided inside with three compartments of equal volumes, disposed lamellary on their length. Ballistic gel was introduced in the lateral compartments of the screens and air in the middle compartment. The screens were placed one over the other on the ground, on the smallest dimension (on thickness) and approached one to another to form a bigger screen. The screen was embedded into the ground with 3 cornier bars and a Kevlar anti-blow blanket was disposed behind the screen, having the thickness of 1,5 cm and the surface of 1,5 m² (fig. 11). In front of the screen, on the ground, at a 2m distance, two explosive charges weighing 0,4 and 10 kg TNT respectively, were placed and detonated successively. On the entire surface from the screen of the 10 kg TNT explosive charge was disposed a 2 kg charge of nails, with an average mass of 1 g.

The method of determination of the explosion pressure and of overpressure on the detonation in the field of the explosive materials is described in the specific procedure Ps-LIPBP-05 of the Laboratory of Tests for Ballistic Protection and Pyrotechnics within the Scientific Research Center for CBRN Defense and Ecology, accredited by RENAR.

A special data acquisition software, designed for this purpose, was used to measure the overpressure in the shock wave front.

The explosion pressure measurement equipment represents a multi-channel system of analog - digital acquisition of the functional parameters of the explosive means, composed of: signal conditioner; PICOSCOPE 3424 oscilloscope; notebook; piezoelectric pressure transducers**,** characterized by the maximum value of the pressure which it can measure and

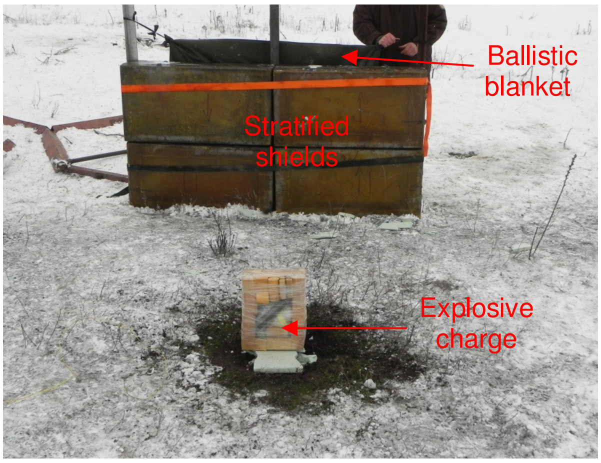

Fig. 11. Front view of the disposal of the explosive charge from the screen.

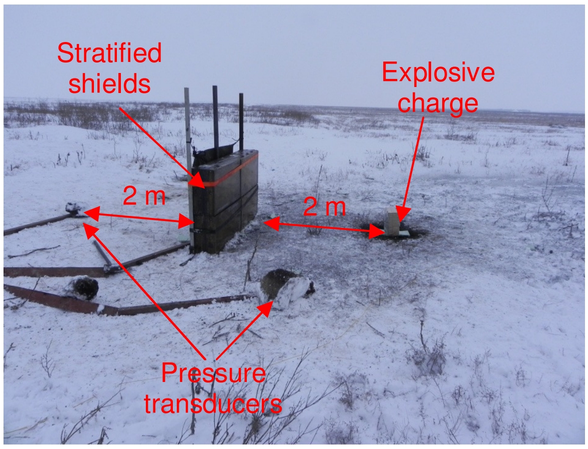

Fig. 12. Side view of the disposal of the explosive charge from the screen.

its sensitiveness, measured in [pC/V] or [bar/V]; low-noise coaxial cable with BNC connectors, used to realize the connection between the piezoelectric pressure transducers; the signal conditioner and the oscilloscope.

The technology used consisted in the placement on the ground, in steel supports, of 2 PCB, model 102, piezoelectric pressure transducers: the first one in front of the screen, 2 m lateral from the explosive charge and the second one, 2 meters behind the screen. (fig. 12). The sensors were disposed on axes of different directions. The piezoelectric pressure transducers, calibrated for different pressures (13,945 bar/V, 6,812 bar/V), were disposed from the explosive charge inversely proportional with the distance to it, with the purpose of complying with the pressure stress. Before the actual execution of the experiment, on the same placement, was executed the explosion of a 400 g TNT charge, for the verification of sensors and the calibration of the registration devices. After the calibration of the devices, a 10 kg TNT parallelipipedic explosive concentrated charge was detonated in the same place as the first explosion. The climatic conditions during the performance of the experiment were: 5 cm thick snow layer, air temperature -2 °C, cloudy sky, moderated wind 2-3 m/s from N-E.

3.2. The interpretation of the effects obtained following the explosion for the fulfillment of the proposed targets

Following the explosion of the 10 kg TNT charge, due to the blow, the four screens were projected and scattered on a distance of approximately 10 m as from the initial position. Two screens were dismantled in the constituent parts (then ones in contact with the ground) and the other two suffered cavity breaks but were not dismantled. An apparent crater, with a diameter of 3 m and a supply area with an irregular surface, on approximately 200 m^2 resulted on the explosion site. From the analysis of the explosions' effects over the screens resulted that the splinters projected by the explosion were mainly retained from the screens and only few of them penetrated the screens.

The latter had no more sufficient energy and were stopped by the anti- blow blanket without being planted in it. The anti - blow blanket suffered no damage, but was projected by the explosion blow at an appreciable distance as from its initial position (it was retained by the reinforced concrete construction situated behind the screen, at approx. 15 m from the explosion's location).

The measurements performed with the registration equipment of overpressure in the shock wave front showed that the stratified screens disposed within the radius of the total destruction area realize a significant attenuation of overpressure in the shock wave front, the maximum pressure measured by the sensor placed 2 m away behind the screen having a value of approximately 80 mbar (fig. 14) under the limit of the minimum value to produce personal injuries of approx. 350 mbar (2). The pressure recorded by the transducer disposed at 2 m lateral left from the explosion place, was of approximately 18 bars (fig. 13).

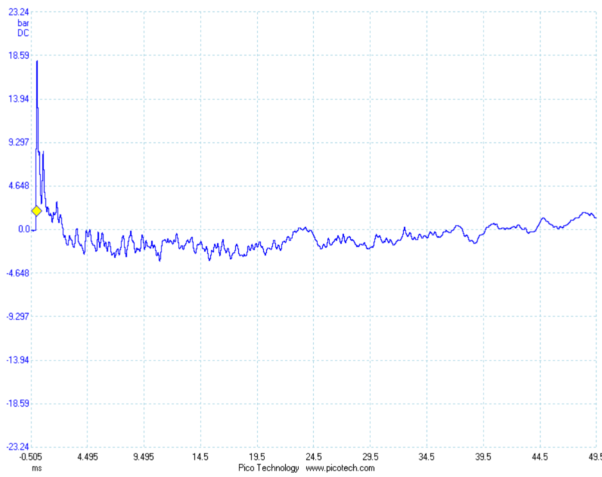

Fig. 13. The record of overpressure in the shock wave front by the piezoelectric transducer, situated at 2 m laterally left from the screen.

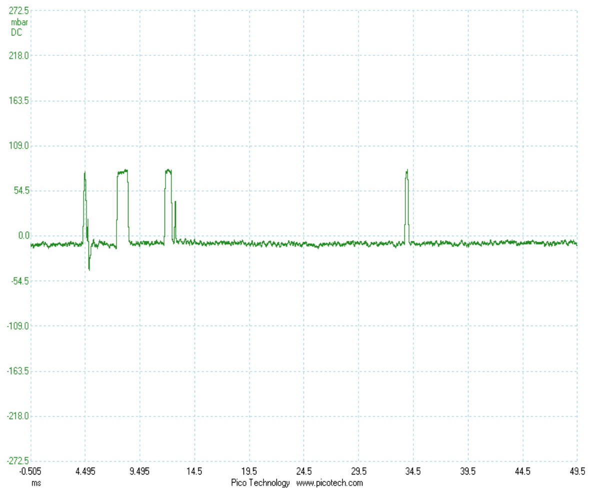

Fig. 14. The record of overpressure in the shock wave front by the piezoelectric transducer, situated at 2 m behind the screen.

Taking into consideration the fact that the screen was placed at a much smaller distance (2 m) from the radius of the explosion's total destruction area, which is of 5 m, it did not resist to the blow effect, turned down and the embedding metallic splinters were pulled off from the ground. The big screen attenuated the splinters' kinetic energy very much but, due to the projection of the 4 screens and the dismantling of certain constituent parts of it, gave birth to dangerous projections.

3.3. The interpretation of the records performed during the explosion for the fulfillment of the proposed targets

After the interpretation of the registrations performed during the experiment, it was found that the overpressure in the shock wave front, 2 m behind the screen, at the ground level, was strongly attenuated to approx. 80 mbar in accordance with fig. 14, under the limit of the minimum value to produce personal injuries of approx. 350 mbar (2). At 4 m from the explosion of a 10 kg TNT explosive charge, without having protection screens, the overpressure in the shock wave front has an approximate value of 2,3 bar (fig. 6) and is lethal (2). A building disposed at 4 m from the ground explosion of 10 kg TNT suffers irremediable damages (according to table 3).

If the building is protected by a screen similar to that used in the experiment, under the same conditions, the damages produced to the building by the overpressure in the shock wave front upon the charge's explosion would be situated at the lower limit of destruction of wood or GFC (*BCA*) walls of ordinary houses (2).

Making a comparative analysis of the analytically obtained values of the overpressure in the shock wave front, to the experimentally obtained values, we can notice that they have contiguous values and it results that the simulation of the attenuation of overpressure in the shock wave front, presented at chap. 2 of the paper is valid.

From the presented data, it results that a building disposed at 4 m from the explosion of a 10 kg TNT explosive charge, protected at the middle of this distance by a triple pluristratified screen, with an approximate thickness of 30 cm, composed of elements of the same thickness but with different densities (ballistic gel – air – ballistic gel), suffers several types of damages to the action of overpressure in the shock wave front.

These consist in windows pulled out, plastering fallen, insignificant damages or destructions on the wood or GFC (BCA) walls.

From the point of view of the explosion's blow effect, the building can be protected if the screen remains embedded in the initial position.

Table 2. *Maximum pressure recorded by the two pressure sensors during the explosion*

Pressure/ disposal sensor	Sensor 1 disposed at 2 m from the explosive charge and laterally from the screen	Sensor 2 disposed at 4,3 m from the explosive charge and at 2 m behind the screen
Maximum pressure	18 bar	0,08 bar

After following the calculations, we evaluated that the fiber glass triple pluristratified screen achieved, at the ground level, 2 m behind it and 4 m from the explosive charge, a reduction of the overpressure in the shock wave front, of approximately 28 times (table 2), as compared to the detonation of the same explosive charge, under the same conditions, without this screen interposed.

In the basis of these data, it results that a triple pluristratified discontinuity plan (screen), composed of homogenous elements with different densities (ballistic gel-air-ballistic gel), placed in the area of an explosion's maximum destruction, in order to protect an area from its effects, realizes a very high attenuation of the overpressure in the shock wave front, 2 m behind the screen.

If, during the explosion, the condition of unaltered maintenance of the initial position of the screen's fixation is observed, the energy released during the explosion is more attenuated. This condition may be achieved by an efficient embedding (fixation) of the screen in the field.

According to table 4, the minimum safety distance for the persons who are not protected against the splinters projected by the explosion of a 10 kg TNT charge, is of 274m (4).

Considering the fact that few splinters penetrated the screen during this experiment and behind the screen the splinters' energy was very low, as it did not produce any damage over the anti-blow blanket, placed immediately behind the screen, it results that the fiber glass triple pluristratified screen, of approx. 30 cm thick, composed of homogenous elements of different densities (ballistic gel-air-ballistic gel) placed in the area of an explosion's maximum destruction, provides an efficient protection of the environment as to the controlled projection of this explosion's splinters.

4. CONCLUSION

The explosion is a phenomenon that occurs in a short time and generates a large volume of gas strongly heated and compressed. Violent impact of the detonation products with environment, gives rise to shock waves. The destructive effect of the explosion is mainly due to its disruptive effect (the effect of the blast and shrapnel) and overpressure in the shock wave front.

The case study carried out in the conditions described above, revealed the following:

- The experiment performed under the above mentioned conditions revealed the provision of a good efficiency of the fiber glass triple pluristratified screens which are composed of homogenous elements of different densities (ballistic gel-air-ballistic gel) in order to attenuate the overpressure in the shock wave front and the propulsion of splinters with an average weight of 1 g, generated by an explosion, in its total destruction area;
- The big screen it is not effective to resist to the blast effect, when is positioned in the total zone destruction of the explosive charge;
- Because the big screen was not sufficiently fixation so as not to it overturn, it gave rise to dangerous projections.

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Table 3. *Damages produced by the explosion over the buildings.*

Explosive quantity [kg TNT]	**Demolition** [m]	**Irremediable damage** [m]	**Remediable damage** [m]	**Minor damage** [m]
Up to 4,5	0,91-1,5	1,5-2,7	6,1	31
5-11,3	1,8-3	3-4,6	9	46
11,8-22,7	3,7	7	15	104
23-68	6	15	31	198
68-113	14	29	58	244
114-227	14	29	58	341
227-454	23	46	91	488

Table 4. *Minimum safety distance for the persons who are not sheltered/ protected during fragment-generating explosions.*

Explosive quantity [kg TNT]	**Safety distance** [m]	**Explosive quantity** [kg TNT]	**Safety Distance** [m]	**Explosive quantity** [kg TNT]	**Safety distance** [m]
0-12,2	274	20,9	325	41	410
12,7	277	21,8	329	43	416
13,6	284	22,7	337	45	427
14,5	290	25	348	57	457
15,4	294	27	357	68	488
16,3	302	30	366	91	533
17,2	305	32	373	136	610
18,1	311	34	384	181	671
19,1	314	36	393	227	732
20	320	39	399		