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EFFECTS OF ORIENTATION, SHAPE, VELOCITY AND MASS OF BLAST INDUCED WINDOW BREAKAGE FRAGMENTS TO WOUND TRAUMA.

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ABSTRACT

The most frequent damage associated to a blast explosion event is the window breakage, for the glasses commonly used there usually are so sensitive to low level load pressures that a small charge of explosive can generate window breakage in a broad area. Also associated human consequences such as injuries and fatalities are related to aspects such as glazing fragment sizes and shapes, thrown distances, propelled impact and number of fragments per unit area. Although many of these aspects have already been extensively studied there is relatively little information on the effects caused to wound trauma. Many relevant information related to the effect of fragments in producing skin penetration and laceration still need deeper investigation. This work deals with aspects of the penetration potential of glass fragments. The experimental setup consists of an explosive charge placed in front of a building where a glass window panel is positioned along the axis of the explosive charge. The generated blast wave loads the glass window breaking it in several fragments. Behind the window there is an optical system to assist the evaluation of the cloud fragments mean velocity along with a special foam that collects and "freezes" some of those fragments. This allows the identification of aspects such as the orientation, shape, velocity, and mass of the fragments as compared to the frequency of deep penetration. In this testing procedure the effects of the standoff distance and of the type and dimensions of the glass panels are also investigated.

Introduction

When an explosive charge detonates, it generates a shock wave that moves thorough it. This wave eventually reaches the interface between the explosive material and the surroundings, usually air.[1,2] At this point , the energy developed by the explosion transfers to the air, compressing it and pushing it outwards from the center of the blast, creating a pressure pulse. Along with the fragments produced by the explosive charge, this pressure pulse plays a predominant role in the damage imparted by the explosive. Behind the zone of compressed air a rarefied region is established , so that a low pressure zone is associated with the pressure pulse. This air-blast system is illustrated in figure 1 .

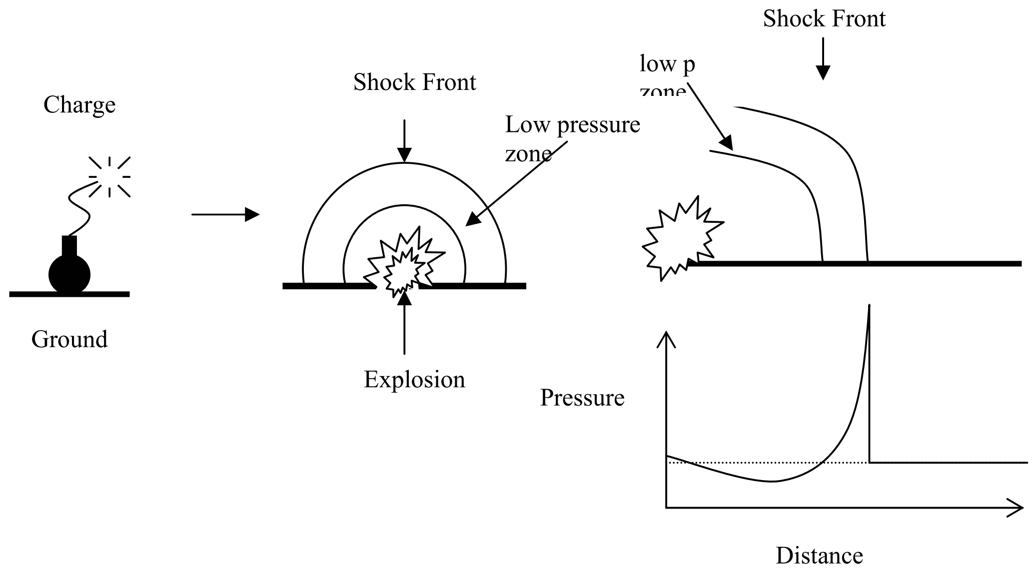

Figure 1 : Illustrative example of the air-blast system [1]

The most frequent damage associated to a blast explosion event is the window breakage,[3] for the glasses commonly used in this manner usually are so sensitive to low level load pressures that a small charge of explosive can generate window breakage in a broad area.

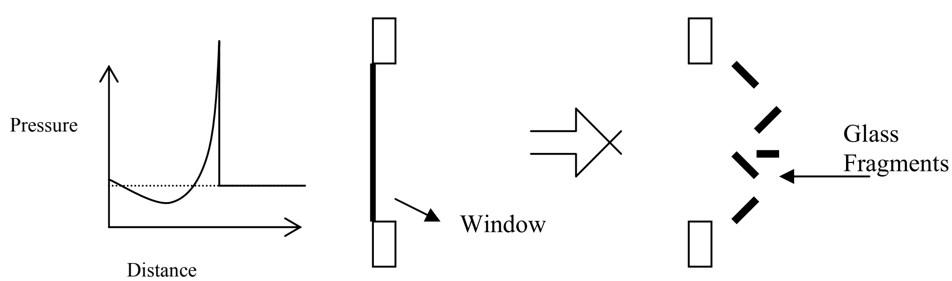

Figure 2 : Window breakage due over pressure effects. [3]

Also associated human consequences such as injuries and fatalities are related to aspects such as glazing fragment sizes and shapes, thrown distances, propelled impact and number of fragments per unit area.[2,3,4] Although many of these aspects have already been extensively studied there is relatively little information on the effects caused by wound trauma. Many relevant information related to the effect of fragments in producing skin penetration and laceration still need deeper investigation [2,3] .This work deals with aspects of the penetration potential of glass fragments.

Experimental Setup

The experimental setup consisted of an explosive charge placed in front of a building where a glass window panel is positioned along the axis of the explosive charge as shown in Figure3. The generated blast wave loads the glass window breaking it into many fragments. Behind the window there is an optical system (Figure 4) to assist the evaluation of the cloud of fragments speed along with a special foam that collects and "freezes" some of those fragments (Figure 5). This allows the identification of aspects such as the orientation, shape, velocity, and mass of the fragments as compared to the frequency of deep penetration. In this test procedure the effects of the standoff distance and of the type and dimensions of the glass panels are also investigated.

Figure 3 : View of an explosive charge positioned in front of the window

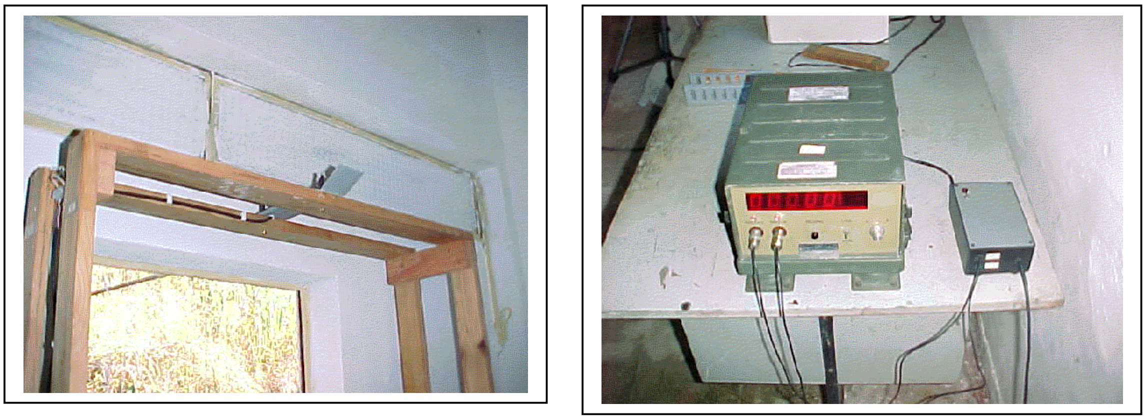

Figure 4 : Views of optical system and Chronometer

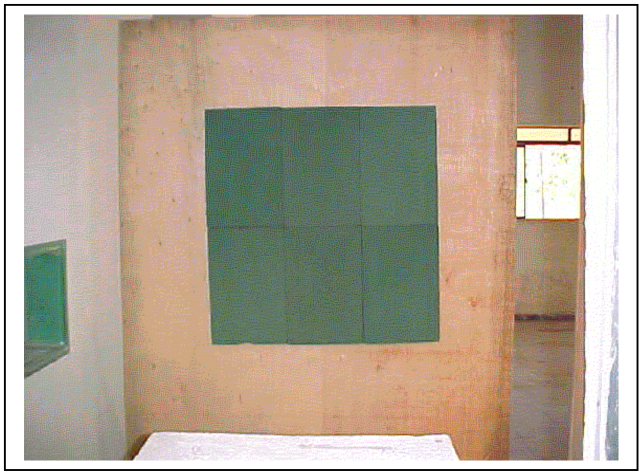

Figure 5 : View of foam panel fixed on a wood support

Figure 6 : General view including optical system, foam , wood support and chronometer.

Problem Description:

It is possible to describe the phenomena taking place from the arrival of the blast wave on the window up to the final deformed foam through the following steps:

1. Glass breakage of the window due to the action of the overpressure .
2. Acceleration of the glass fragments by overpressure action.
3. Interaction of the blast wind with glass fragments.
4. Impact of the glass fragments on the foam.

The impacts can be summarized at the following categories:

1. Horizontal impact with penetration, the fragment possessing an arrival angle of incidence of nearly 90°.
2. Vertical impact or flat surface impact, the fragment possessing an arrival angle of incidence of nearly 180°.
3. Angular impact with penetration, the fragment possessing an arrival angle of incidence of nearly 45°.
4. Accentuated impact, the fragment first performing first an angular or horizontal impact then receiving a flat or vertical impact from another incoming fragment which will accentuate its penetration. In several cases it were found many small fragments imbedded deep in the craters of the large ones.

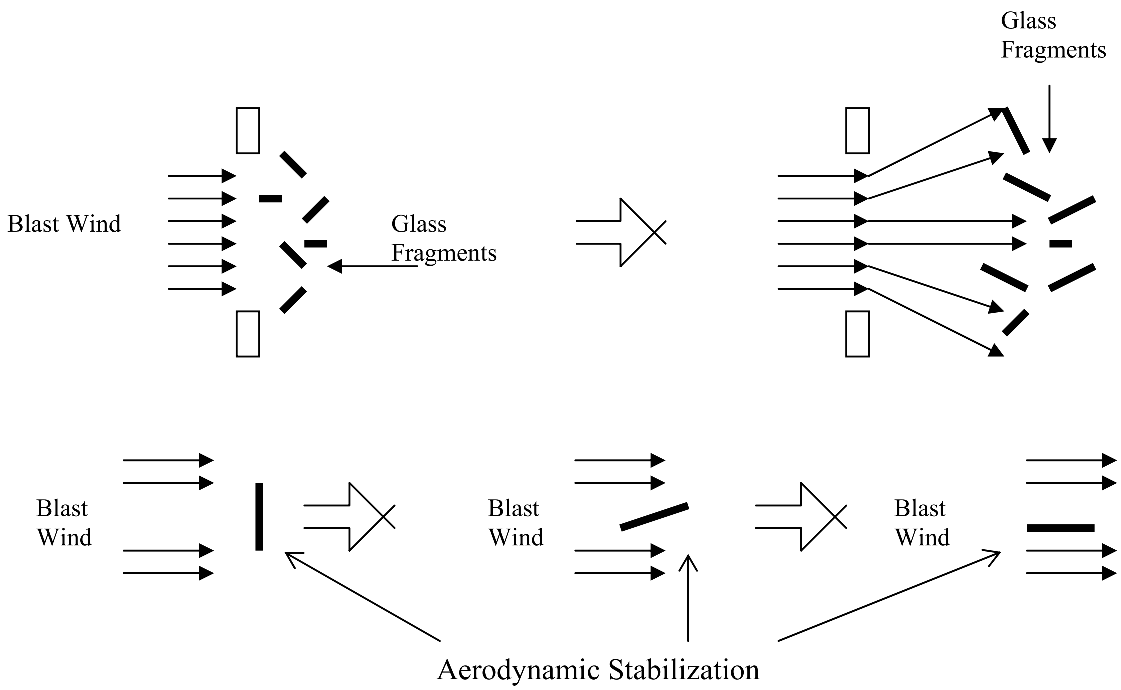

Figure 7: The hypothesis of aerodynamic stabilization.

The first category of impact was found predominant along the axis where the charge was positioned. Maybe this is because the turbulence at this region is so intense due to the blast wind that the glass fragments tend to acquire aerodynamic stabilization.

Category 2 was found also along the axis where the charge was positioned but there it was not predominant. Far from the center of impacts, this category distribution seemed random. the distribution of this category was completely random with the categories 1 and 3. This behavior might be associated with the rotation of the fragments which can be more pronounced where the stabilization effects of the blast wind are less effective.

Category 3 was found to follow the tendency of category 2, for the same reasons.

Category 4 is singular. At this particular situation, slower fragments, which do not have enough energy to achieve a complete penetration in the foam, undergo a horizontal impact on the foam and then a larger fragment impacts over it, giving it the needed energy to perform a complete penetration in the foam, just like a “nail and hammer” action.

Finally Figure 8 displays two views of the foam panel with imbedded fragments of those categories

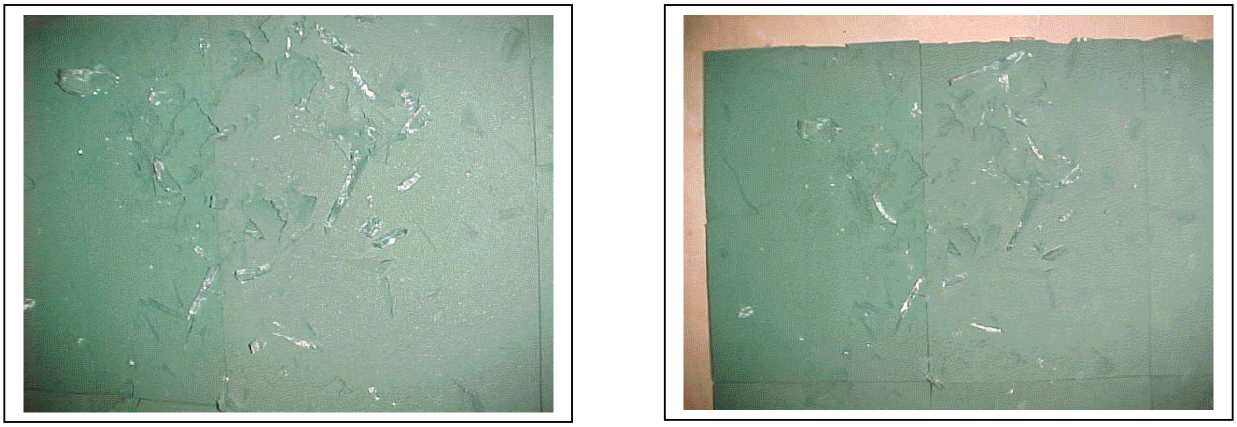

Figure 8 : Views of the foam panel with imbedded fragments

Penetration Model

This foam was chosen due to its constant compression pressure response, P_C, which allows to relate its total deformation volume to the kinetic energy, E_C, of the fragments. Hence the deformation work, W_{DW} , can be written as

$$W_{DW} = \Delta E_C = \int_0^x [P_C . A] . dx$$

$$W_{DW} = P_C \int_0^x A . dx \qquad (\text{if } \ P_C = \text{constant})$$

$$W_{DW} = P_C . V$$

$$P_C = \frac{W_{DW}}{V} = \frac{\Delta Ec}{V}$$

where A is the fragment generated deformation cross section area and V, its volume.

P_C was estimated by dropping a metallic body with known dimensions and weight from known different heights on the foam surface. These measurements along with the above mentioned assumptions yielded the graph shown in Figure 9 which displays the compression pressure with the penetration depth in the foam. It can be seen that the compression pressure is nearly constant and may be taken to be equal to 0.132 J/cm^3 up to a depth of 4.5 cm.

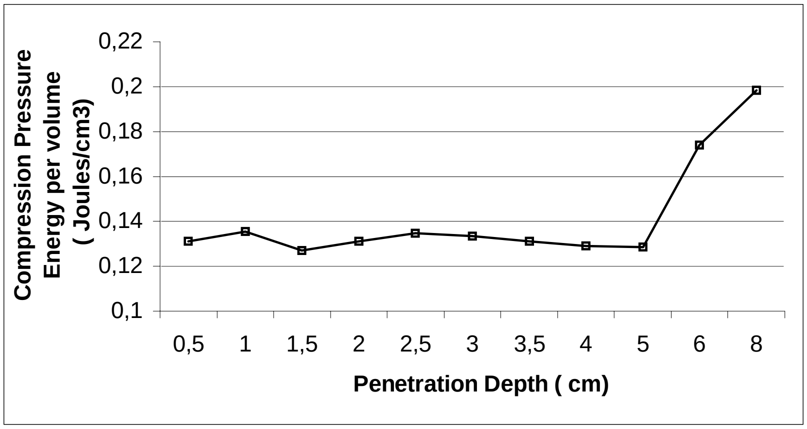

Figure 9: Foam compression pressure versus penetration depth

The knowledge of the weight of the retained fragments in the foam along with their respective penetration volume allowed the comparison of the mass of fragments with their total kinetic energy, as shown in Figure 10, for an initial mean velocity of 63 m/s and fragment capture 2 meter away from the glass panel with a mean arrival velocity of 9.5 m/s. The explosive charge consisted of 0.3 kg of cast TNT placed 0.45 m away from the window, as suggested in Figure 3. Figure 11 displays the behavior of the fragment flight for an initial mean velocity of 349 m/s and fragment capture 2 meter away from the glass panel with a mean arrival velocity of 14.1 m/s . Here the explosive charge consisted of 0.9 kg of cast TNT placed 1 m away from the of window, as suggested in Figure 3.

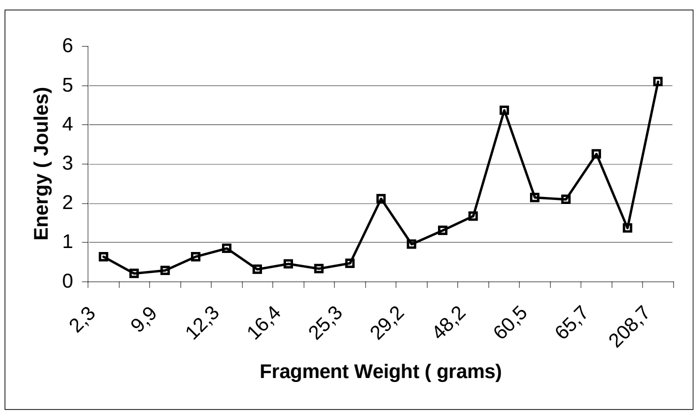

Figure 10 : Fragment weight versus kinetic energy, for a 6 mm thick glass panel

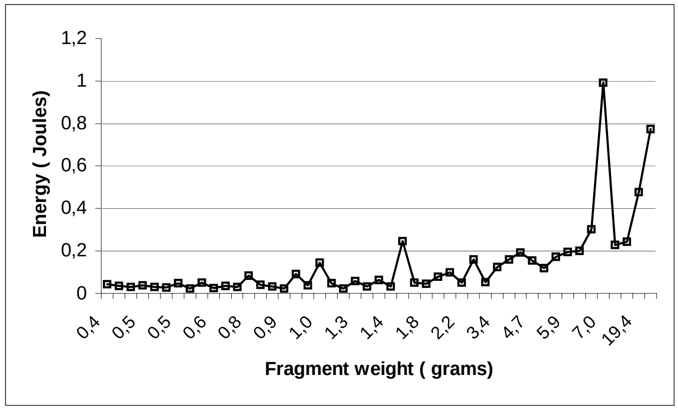

Figure 11: Fragment weight versus kinetic energy, for a 3 mm thick glass panel

The impact velocity can also be estimated (from fragments kinetic energy and mass considerations), yielding the graphs shown in figures 12 and 13 for the geometry and charge positioning described above for figures 10 and 11 respectively

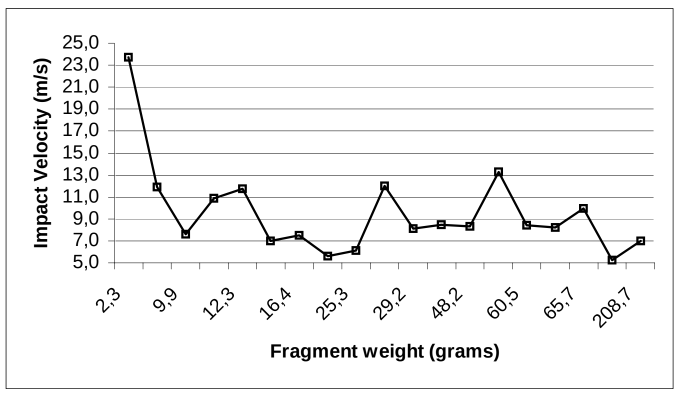

Figure 12: Fragment weight versus impact velocity, for a 6 mm thick glass panel

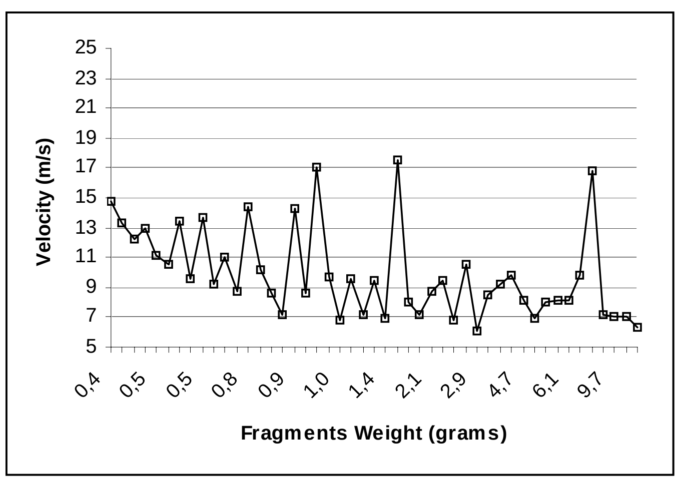

Figure 13: Fragment weight versus impact velocity, for a 3 mm thick glass panel

The spreading noticed on the velocity distribution graphs are due to the drag forces acting on fragments of different shape and flying attack angle and possibly to impacts among flying fragments which might even act as in a hammer like effect pushing early arriving fragments deeper into the foam. Notice also that light fragments which penetrated the foam were found inside craters of larger fragments.

Conclusions:

The experimental setup consisted of an explosive charge placed in front of a building where a glass window panel was positioned normal to the axis of the explosive charge. The generated blast wave loaded the glass window breaking it in many fragments. Behind the window there was an optical system to assist the evaluation of the cloud fragments speed along with a special foam that collected and "froze" several of those fragments .

The impacts displayed the following behavior:

Horizontal impacts with penetration were found predominantly along the axis where the charge was positioned. This might be because the airflow in this region was so intense due to the blast wind that the glass fragments acquired aerodynamic stabilization.

Vertical impacts or flat impacts were found also along the axis where the charge was placed but it was not predominant there. Far from the center of the impacts, the distribution of this category seemed to be completely random. This behavior can be associated with the spinning of the fragments which can be more pronounced where the stabilization effects of the blast wind are less effective.

A kind of accentuated impact was noticed where the fragment first perform a horizontal or angular impact, then receives a flat or vertical impact accentuating its penetration. In many instances it were found little fragments imbedded deeper at the crater of large ones. It seems that at this particular situation the smaller fragments, which do not have enough energy to attain a complete penetration in the foam , perform a horizontal impact on the foam surface, then a larger fragment impact gives it the push (i.e., the energy) needed to achieve a complete penetration in the foam, seemly in a "nail and hammer" fashion.

The foam was chosen due to its constant compression pressure response which could be related to its total deformation volume and to the kinetic energy of the fragments.

Knowing the weight of the foam trapped fragments and their respective penetration volumes it was possible to relate the mass of the fragments with their total kinetic energy. Then the impact velocity was estimated from the fragments kinetic energy and mass.

The spread noticed on the velocity distribution graphs seem to be due to the drag forces acting on fragments of different shape and flying attack angle and possibly to impacts among flying fragments which might even act as in a hammer like effect pushing early arriving fragments deeper into the foam. Notice also that light fragments which penetrated the foam were found inside craters of larger fragments.

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