Calculating Blast-Effects Distances in Urban Environments

by

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Introduction

EBlast®[1] (Emergency Blast), an expert system to assist emergency measures personnel determine appropriate evacuation distances from explosive devices in urban environments, was described and demonstrated at MABS15 (Dewey et al, 1997) and MABS16 (Dewey and McMillin, 2000). The ***EBlast*** user is able to select from a wide range of explosive devices, such as vehicle, package and pipe bombs of different sizes, and military munitions, and to define an urban environment in which the device is located. The expert system then provides the limiting distances at which various blast effects are likely to occur. The blast effects include such features as: percentage probability of lethality; damage to concrete or brick structures; eardrum injury, and damage to various types of window glass. The limiting distances of these effects are displayed numerically and graphically on a bar chart, or superposed as circular contours on a city map stored as a geographical information system (GIS). The Alcohol, Tobacco and Firearm Bureau's (ATF) recommended evacuation distance for the selected explosive device, is also displayed.

Users, and potential users, of ***EBlast*** have asked how the blast-effects distances are calculated. Also, why the distances for the various effects do not always occur in the same order if the size of the explosive device or the nature of the urban environment are changed. The objective of this paper is to answer these questions.

Damage/Injury Criteria

When a structure or a person is exposed to a blast wave, damage and injury usually result from the loading caused by the hydrostatic and the dynamic pressures. The horizontal flat roof of a buried structure will only be loaded by the hydrostatic pressure, whereas a power pole can withstand a very large hydrostatic pressure, but may be broken by the dynamic pressure of the blast wave. A standing structure or person will be damaged or injured by a combination of the effects of these two types of loading. The degree of damage or injury will be related, not only to the peak values of these pressures, but also to their durations or impulses, defined as the time integrals of the pressures during their positive phases. As a result, a specific amount of damage or injury will occur at a higher peak pressure from a small explosion than from a large explosion with a longer positive-phase duration.

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[1] ***Eblast*** and ***AirBlast*** are trademarks of expert systems by Dewey McMillin & Associates Ltd, Victoria, BC, Canada

A specific level of damage or injury will be associated with the peak values and impulses of both hydrostatic and dynamic pressure. Fortunately, in the case of a classical blast wave, there are direct relationships between the peak values of the hydrostatic and dynamic pressures, and between their impulses. As a result, most types of damage and injury caused by blast waves can be related to the peak value and impulse of hydrostatic pressure only, even though the hydrostatic pressure may not be the primary cause of the damage or injury.

During the period from the beginning of the Second World War to the present, much information has accumulated about damage levels caused by explosions from devices with a wide range of energy yields, covering many orders of magnitude. The energy yield of an explosion is usually quoted in terms of the equivalent mass of TNT, in pounds, kilograms or kiltoton(ne)s. Knowing the distance of a structure from the explosive source, at which damage did or did not occurred, and the TNT equivalent charge mass, the peak hydrostatic pressure and its impulse can be determined at the location of the structure. Plotting many such results in the pressure-impulse plane provides two families of points: those at which damage occurred and those at which it did not occur. The two families can be separated by a curve, which usually resembles a rectangular hyperbola. Such a curve is called the damage/injury criterion for the specific blast effect. The form of such a damage-criterion curve is shown in figure 1.

The most simplistic damage/injury criterion, such as that used by the Alcohol, Tobacco and Firearm Bureau to determine the recommended evacuation distance, uses only the peak pressure. Many of the peak-pressure criteria are based on results from nuclear explosions, for which the blast waves had very long durations. Therefore, such criteria are valid only for large explosions, or for structures with high-frequency responses. A large structure exposed to a blast wave from a small device will be damaged only by much higher pressures than predicted by the "peak pressure only" criterion.

In developing the ***EBlast*** expert system, damage/injury criteria curves were created for about twenty different blast effects. Some data were available from the authors' own files resulting from their participation in a large number of high explosive tests during the past 45 years. As many data as possible were gathered from the literature, dating back to the Second World War. The earlier data were particularly useful because they related to small and intermediate sized conventional explosions, the primary emphasis in ***EBlast***, rather than nuclear explosions, from which much of the later data were derived. Some of the most recent data are difficult to access, for security reasons, and difficult to interpret for a broad analysis because they were obtained from tests using specific devices and targets, and with fewer free-field measurements of blast wave properties.

Blast-Effects Distances

EBlast converts the explosive device, selected by the user, to the equivalent TNT surface burst charge. ***AirBlast***® is then used to calculate the variations with distance of both the peak hydrostatic pressure and the hydrostatic-pressure impulse for the TNT charge. ***AirBlast*** is an expert system that uses a large database of experimental measurements to determine the physical properties of the blast waves produced by free-air, surface-burst and height-of-burst explosions. The peak hydrostatic pressure, P, and the hydrostatic pressure impulse, I, can thus be expressed as functions of the distance from the explosion, R, i.e. $P = f_1(R)$, and $I = f_2(R)$. Eliminating R from these two relationships provides P as a function of I, for the selected TNT equivalent charge mass. This relationship can be plotted in the pressure-impulse plane, where it will intercept the damage/injury criteria curves for the various blast effects, as shown in figure 2. The pressure and impulse at an intersection point can be used in functions f_1 or f_2, above, to determine R, the limiting distance at which the blast effect is expected to occur. The intersections of the pressure-impulse relationship with the various damage/injury criteria curves provide the limiting blast-effects distances that are displayed by ***EBlast***.

Influence of Urban Environments

The influence of different urban environments on the physical properties of the blast waves produced by various masses of surface-burst TNT, have been calculated by numerical simulation using the AWAF (Adaptable Weighted Average Flux) program (van Netten, 1997). AWAF simulates the detonation of a TNT charge with a high-pressure high-temperature sphere of gas, for which the rate of energy release can be controlled. The initial pressure and temperature, and the rate of energy release, are selected so that AWAF exactly reproduces the blast wave properties obtained from ***AirBlast*** for the selected surface-burst TNT charge. The same initial conditions can then be used to simulate the blast wave in various urban environments, assuming all structures to be rigid during the passage of the blast wave.

The peak hydrostatic pressure and hydrostatic-pressure impulse are calculated at each grid point in the simulation. The maximum pressure and maximum impulse at each radius are determined and used to establish modified functional relationships, $P = m_1(R)$, and $I = m_2(R)$. The maximum pressure and maximum impulse at a specific radius may not occur at the same place in the calculational grid. Also, there may be no single radial along which $P = m_1(R)$ or $I = m_2(R)$ will exist. This always provides the "worst case scenario" at any distance from the explosion. Eliminating R from m_1 and m_2 provides a modified pressure-impulse relationship for the urban environment. The intersection of this curve with the damage/injury criteria curves establishes the blast-effects distances to be expected in the urban environment. This is illustrated in figure 3.

Some Unexpected Results

Users of ***EBlast*** observed that the program sometimes produced results that they did not expect. For example, the order of the distances that some blast effects occurred, relative to the ATF recommended evacuation distance, would change with the size of the explosive device. This is because ***EBlast*** uses pressure-impulse damage/injury criteria, whereas the ATF evacuation distances are based only on a peak pressure value. The effect is illustrated in figure 4, in which are plotted a pressure-impulse damage/injury criterion curve, a peak pressure only line, and the pressure-impulse relationships for two charge masses. The pressure-impulse curve for the smaller charge mass intersects the damage/injury criteria curves to the left of their intersection. As a result, the distance for the blast effect predicted by ***EBlast*** is shorter than that predicted by the peak-pressure-only criterion. In contrast, the pressure-impulse curve for the larger charge intersects the damage/injury criteria curves to the right of their intersection. Now, the distance for the blast effect predicted by ***EBlast*** is larger than that predicted by the peak-pressure-only criterion.

A similar result may occur in situations in which different damage/injury criteria curves intersect in the pressure-impulse plane, as illustrated in figure 5. These curves are intersected by the pressure-impulse curves for a specific charge mass on flat ground, and for the same charge mass in an urban environment. Because the intersections occur in different regions, the order of the blast-effects distances is reversed.

For clarity, the curves in figures 1 to 5 have been generated for illustration purposes only. In contrast, figure 6 shows actual damage/injury criteria curves used in ***EBlast***, and the pressure-impulse curves for a 278 kg surface-burst charge on flat ground and in an urban environments with several different building heights.

Some Lessons Learned

Searching for apparent anomalies in the results produced by ***EBlast***, and performing many simulations of blast waves in various urban environments, has taught a number of lessons. Some of these are listed below, although they have not all been described in the present paper.

(a) It is important to use pressure-impulse damage and injury criteria rather than a single peak-pressure criterion. Peak pressure criteria have been developed usually using relatively large explosions, and may not be valid for predicting the effects of smaller explosions.

(b) The effects of an urban environment on the physical properties of a blast wave may not be immediately obvious. For example, an explosion at a T-junction produces the maximum blast effects along the side arms and not along the main stem.

(c) An urban environment always enhances and never diminishes the effects of an explosion.

(d) Street width and building density are of importance in the immediate vicinity of an explosion, but have lesser effects at greater distances.

(e) Building height is important up to about 30 m, but beyond that has little effect, except for very large explosions. This is because the blast wave first feels the effect of the building height when the rarefaction wave, produced as the shock diffracts over the building, returns to ground surface. For tall buildings, this occurs after the positive phase of the blast wave has past.

References

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Figures

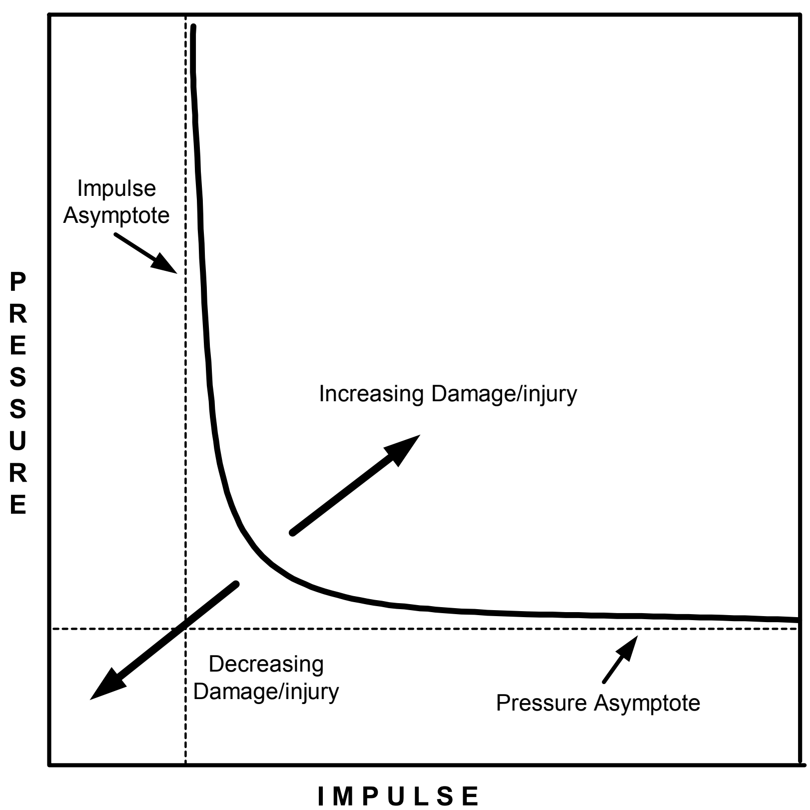

Figure 1. Damage/injury-criterion curve in the pressure-impulse plane. The curve, in the form of a rectangular hyperbola, indicates the limiting pressures and impulses at which the specific level of damage or injury is expected to occur.

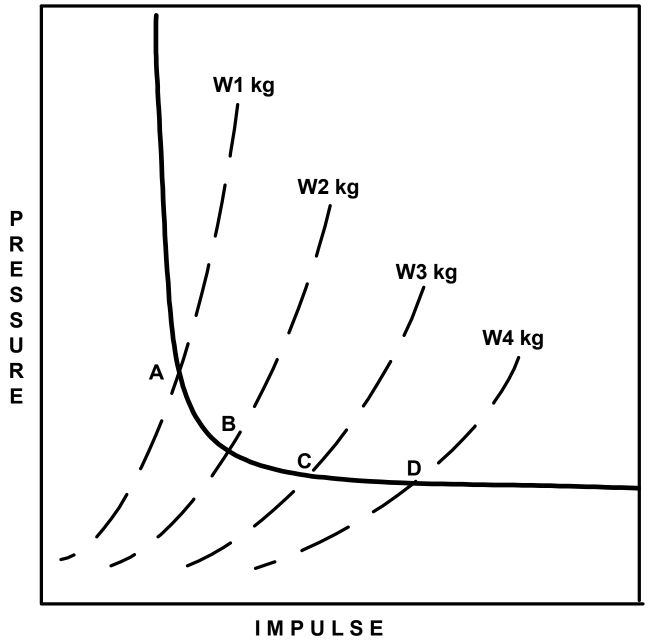

Figure 2. Damage/injury-criterion curve intersected by pressure-impulse relationships for explosions of different charge masses, where $W_1<W_2<W_3<W_4$. The pressures at the intersection points, A, B, C and D can be used in the pressure-radius relationship for each charge mass to determine the limiting distances at which the damage/injury will occur.

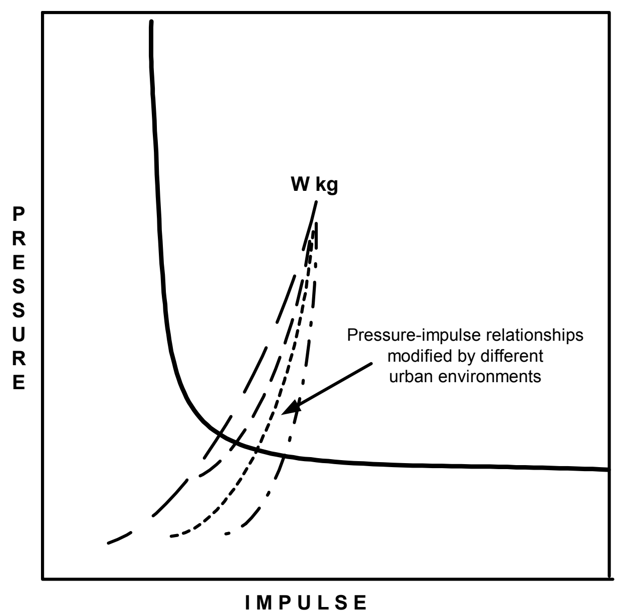

Figure 3. Damage/injury-criterion curve intersected by pressure-impulse relationships modified by various urban environments

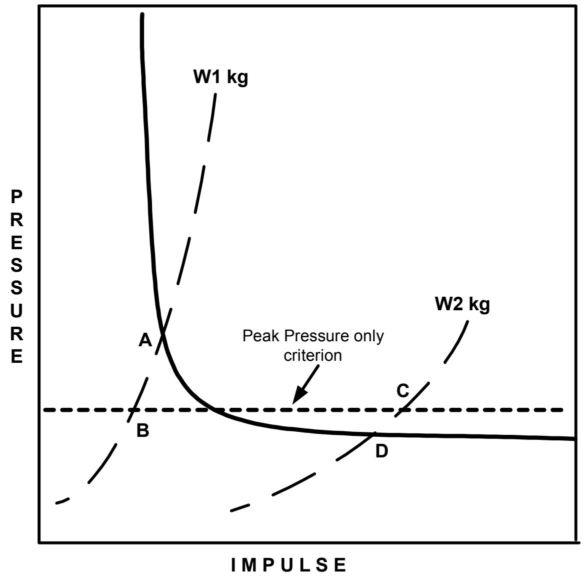

Figure 4. Damage/injury and pressure-only criteria intersected by pressure-impulse relationships of different charge sizes. For charge mass W_1, the pressure-impulse criterion will predict a shorter distance (A) than the peak-pressure-only criterion (B). For charge mass W_2, the peak-pressure-only criterion (C) will predict the shorter distance.

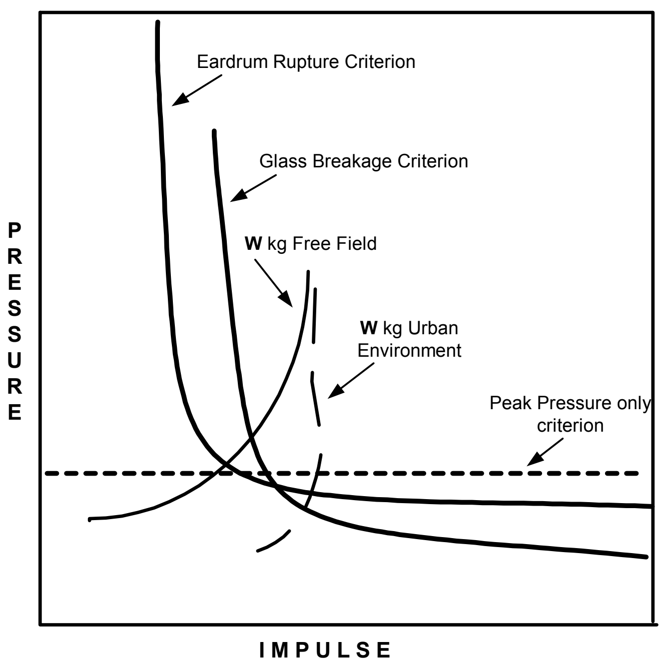

Figure 5. Three damage/injury-criterion curves intersected by pressure-impulse relationships for different urban environments. The order in which the blast-effects distances occur are reversed for the two environments.

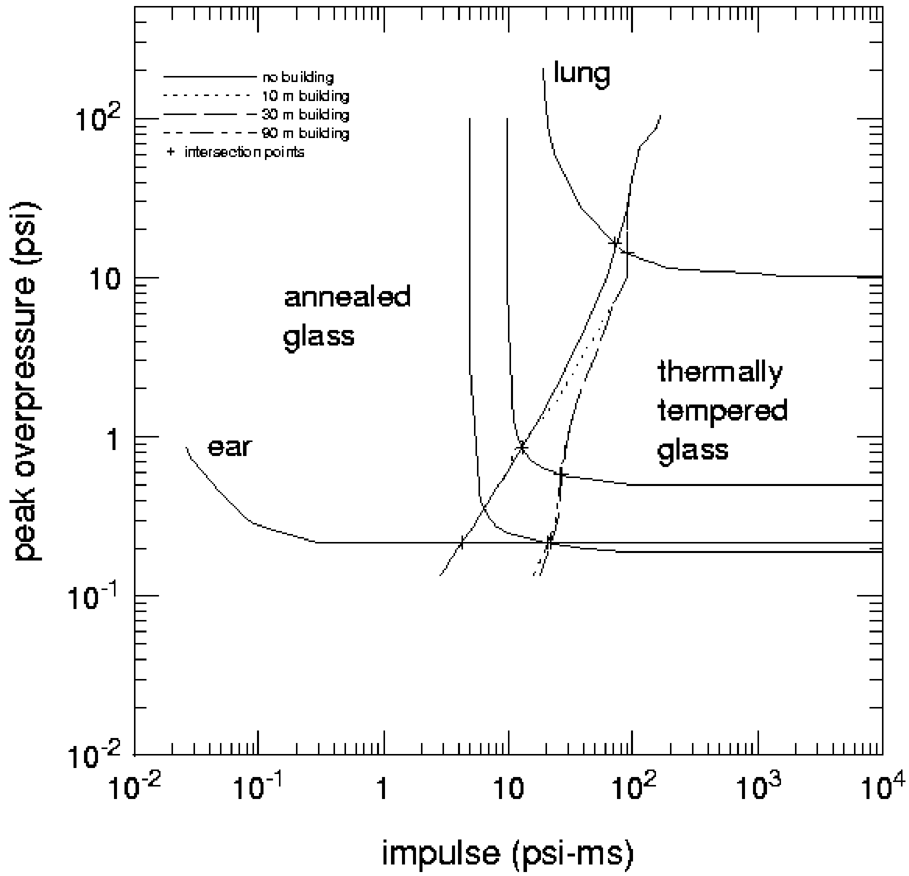

Figure 6. Some damage/injury-criterion curves as used in ***EBlast***, intersected by pressure-impulse relationships for a 278 kg surface-burst TNT explosion in an urban environment with different building heights.