THE ASSESSMENT OF MAJOR HAZARDS: THE LETHAL EFFECTS OF A CONDENSED PHASE EXPLOSION IN A BUILT-UP AREA

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For installations handling explosive materials there is a requirement for the purposes of hazard assessment for methods which give an estimate of the lethality of an explosion in a built-up area. A model for the lethal effects of a condensed phase explosion is derived, based on a simplified classification of explosion fatalities into primary and secondary deaths. Primary deaths occur almost entirely in the near field and are due to the direct effects of the blast, secondary deaths occur in both near and far fields and are associated with building damage. The model consists of correlations for primary and secondary deaths as a function of mass of explosive and distance. The application of the model to vapour cloud explosions is briefly discussed.

INTRODUCTION

The assessment of a major explosion hazard involves the determination of the effects of the explosion on people. There are available some data on the effects on people in the open for some particular injury modes, including eardrum rupture, lung haemorrhage, bodily translation, missile impact and so on, but these are of limited use without guidance on their use to determine the overall mortality. Moreover, in most accident situations the majority of people will be indoors, but again there is little information available in usable form on the effects of explosion on people in buildings.

The approach adopted here is to combine the use of experimental work on the effect of blast on animals and historical data on injury associated with housing damage. In the near field a relation is derived for primary causes of death arising from the direct effects of blast, while in the near and far fields a relation for secondary causes is based on the correlation of fatalities with housing damage. The paper gives a model for the lethality of explosions in built-up areas based on these primary and secondary causes of death.

The model is intended primarily for the assessment of the hazard of an explosion which occurs in the open. It is applicable to condensed phase explosions only. The same general approach may be applicable to vapour cloud explosions also, but this aspect, though briefly discussed, is beyond the scope of the paper.

The variability between individual explosions of the same nominal energy, both in respect of the overpressures measured and the casualties and damage caused, is well known. It is emphased, therefore, that the model derived is intended for the estimation of average effects.

BACKGROUND

As a result of the development of aerial bombing of civilian populations during the Second World War investigations of the effectiveness of bombs were undertaken by both sides. Since the war further extensive studies have been carried out with particular reference to the effects of nuclear weapons.

In the UK Professor Zuckerman played a leading role in work sponsored by the Ministry of Home Security in 1939-41 and wrote a number of papers (1-3). He was involved both in air raid casualty surveys and in experiments in which animals were exposed to the effects of blast. The Germans also did work on blast effects (4).

In the US during the 1960s and 1970s a large programme of research was carried out at the Lovelace Foundation on the effects of blast on animals and on the application of the results obtained to man with particular reference to nuclear weapons (5-9).

The behaviour of blast waves has also been extensively studied. For condensed phase explosives, i.e. high explosives such as TNT, correlations are available for the estimation of the blast wave characteristics as function of the mass of explosive (e.g. Baker *et al* (10)). Other relations are available which correlate housing damage with mass of explosive (11,12).

Blast Wave Characteristics

The characteristics of the blast wave from the explosion of a condensed phase explosive such as TNT have been the subject of a number of studies, of which reference may be made to some of those most frequently quoted (13-23). A full account is given by Baker *et al* (10).

The blast wave parameters such as overpressure, impulse and duration time are correlated, using scaling laws, in terms of scaled distance. There are a number of correlations which give broadly similar results. The overpressure correlations show a degree of experimental scatter. A plot showing the results obtained by various workers is given in Baker *et al* (their Figure 2-3).

The usual relation is for free air explosions. For an explosion at ground level it is necessary to multiply the actual mass of explosive by a factor which takes account of the reflection of the blast by the ground. For an explosion in which no crater is formed the factor is 2, but for a condensed phase explosive the factor recommended is 1.8, which allows for crater formation. A factor of 1.8 has been used here. Figure 1 shows the overpressure from a condensed phase explosion as a function of mass of explosive and distance. It has been calculated from the correlations referred to and using the reflection factor of 1.8 just mentioned.

For small charges and duration times use has also been made of the data on blast wave parameters given by Zuckerman (2) for his experiments. Data given by Desaga (4) and by Kingery and Pannill (19) have been used as a crosscheck.

The account of blast effects given below is principally in terms of peak overpressure. The peak reflected pressure is a function both of the peak overpressure and the peak dynamic pressure, which are directly related. The latter is dominant in the near field and the former in the far field.

Casualties in Air Raids

In his work on air raid casualties Zuckerman found that as far as lung damage was concerned it was difficult to distinguish between the effect of the blast wave pressing on the body and that of body translation or impact of missiles on the body. He concluded that fatal casualties which showed little or no external sign of injury would probably only in rare cases have died from the direct effects of blast. Other causes of death in such circumstances are asphyxia following burial, carbon monoxide poisoning and chronic illness aggravated by shock.

Zuckerman pointed out that the overpressure necessary to bowl a person over is only slightly less than that likely to affect the internal organs and that when a person is violently thrown against a hard surface, injuries may occur to internal organs which are difficult to distinguish from those which might have occurred due to the direct blast pressure.

Casualties in Chemical and Gas Explosions

A study of 81 chemical and gas accidents has been made by Settles (23). Of these, 44 involved fire and explosion, 23 fire only and 14 a detonation reaction. Settles states:

> "The 14 accidents in which detonating forces were present resulted in injuries to 35 persons and 34 fatalities. It appears from information available that only one of these 34 deaths resulted from blast overpressures that are associated with a detonating reaction. However, this one fatality was not the result of blast damage to human tissue. Rather, the blast pressure caused this individual to be propelled as a projectile. The other 33 persons who died in these 14 accidents were located at points where the density of flying fragments, and in some cases, the lethal searing of radiant heat were so great that their deaths were certain, even though there had been no blast effects".

It may be noted that although these incidents are presumably typical of industrial explosions, they differ from some other explosions considered in this paper in that there is normally a separation zone between an industrial site and any housing, so that in so far as the nature of the casualties changes with distance, those just quoted may be somewhat different from those which apply to an explosion occurring at random in a built-up area.

Casualty Classifications

From the examination of air raid casualties Zuckerman (2) derived the classification of casualties shown in Table 1.

In the Lovelace Foundation work two modes of injury which were extensively investigated were those due to

1) The overpressure of the blast wave on the body
2) The translation of the body by the blast wave.

The first of theses acts on the lungs so as to cause lung haemorrhage, the second causes injury by decelerative tumbling with flailing of the limbs and/or impact with hard objects.

In an accidental explosion in a built-up area the casualties will fall into two main categories: those in the near field caused by the direct effects of the blast wave (overpessure, translation) and those in both the near and far fields caused by building damage. For the purposes of the assessment of the hazard of such explosions an alternative classification of casualties is therefore proposed, consisting of just two categories, primary and secondary casualties. The primary casualties correspond broadly to Zuckerman's categories 1 and 2 and the secondary category to his category 3. His category 4 refers to fire rather than explosion and is not considered here. The modes of injury mentioned as those principally investigated by the American workers are both in the primary category.