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Prediction of injuries caused by explosive events: A case study of a hand grenade incident in South Africa

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INTRODUCTION

In this case report, a M26 hand grenade containing high energy explosives was found and unintentionally detonated by children who were minding cattle. The police said the device was an M26 grenade of South African origin.

There were several hand grenade incidents reported in the Transkei area since 1998 (See Table 1).

Date of incident	Child deaths	Adult deaths	Type and number of hand grenades involved
03/01/1998	2	0	M26 (x 2)
01/06/1998	6	0	M26 (x 1)
28/12/1998	1	1	Unknown (x 1)
02/07/1999	3	0	M26 (x 1)
28/11/2000	0	0	M26 (x 1)
28/11/2000	0	0	RGD5 (x 2)
02/02/2001	1	1	M26 (x 1)
12/11/2004	0	3	M26 (x 1)
13/04/2005	0	0	Unknown (x 1)
23/08/2006	2	0	M26 (x 1)
18/07/2007	0	0	M26 (x 1)
04/09/2007	1	0	M26 (x 1)

A fragmentation grenade such as the M26 was designed to supplement small arms fire against enemies in close conduct. It produces a complex set of injury mechanisms that cause injury to humans within certain ranges. Wounding mechanisms caused by explosive events can be categorised as follows (White, 1968):

- Primary blast injury (PBI) cased by the direct effects of the blast (blast induced variations in the environmental pressure). This could result in injuries to the lungs, upper respiratory tract, gastrointestinal tract and solid intra-abdominal organs. These injuries could occur when the victim is in very close proximity to a grenade containing high-energy explosives
- Secondary ballistic injuries due to mention fragmentation and flying debris. This is the mechanism by which the M26 grenade is intended to cause injury
- Tertiary injuries are caused by whole body displacement
- Miscellaneous injuries such as burns and toxic fume inhalation. Burns could possibly be caused if the subject was in the fire ball resulting from an explosive event.

Criteria have been developed which relate measurements that can be taken during explosive events to predict possible injury severities caused by the wounding mechanisms described above. In this case, the children were handling the grenade and were thus much closer to the grenade than victims would be under normal operating conditions (i.e. If the grenade was thrown into the general vicinity).

It is well known that the higher the peak pressure caused by the explosive device, the more severe the injuries caused by this pressure will be. It is also accepted that longer positive phase pressure durations result in more severe injuries than if the duration was shorter (Cooper, 1996).

The Bowen criterion is used to predict injuries to the lungs caused by pressure waves in a free field environment (i.e. not in an enclosure or near objects which may cause complex reflected waves to interact with the subject).

An alternative to the Bowen criterion is the chest wall velocity predictor (CWVP) (Axelsson and Yelverton, 1996), which takes into account, not only the lungs, but also the upper respiratory tract, gastrointestinal tract and solid intra-abdominal organs. This criteria was developed to take into account complex blast waves (as one might find if an explosive was to detonated in an enclosed space or near reflecting surfaces), but it is also valid for the free field case.

In this study, a simulation of the M26 hand grenade was performed. By using these simulated pressure profiles at various distances from the grenade, injury criteria were used to predict possible injuries at those positions. The mechanisms of injury resulting from the primary and secondary effects of the explosive event, in relation to the distance of a victim to the grenade, will be discussed.

INCIDENT ANALYSIS

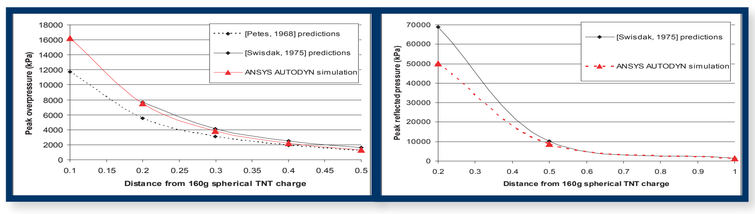
Incident description

At autopsy, all children had their ventral aspects mutilated or greatly lacerated. A bluish green substance was deposited all over the abdomen and chest. The boy closest to the blast sustained abdominal and chest mutilation, while those near him sustained deep lacerations to the torso. The lungs and intestines were diffusely contused in three of the boys. The two boys who were a considerable distance from the blast escaped with minor injuries.

Simulation of the M26 hand grenade and predicted pressures from literature sources

ANSYS AUTODYN2D was used to calculate the pressure at three locations of a 160 g spherical TNT charge that approximates the M26 hand grenade. The explosive and air are modelled with the Euler Gudonov solver in an axial symmetric geometry. The air and explosive gas are allowed to escape across the boundaries. The ideal gas equation of state models the air and the explosive is modelled with the Jones-Wilkens-Lee (JWL) (Lee, Hornig and Kury, 1968) equation of state.

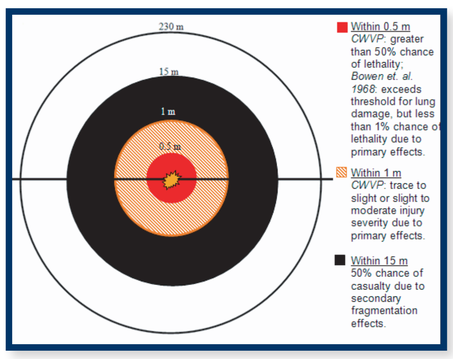
Peak pressure values were obtained from various formulae obtained from literature (e.g. (Petes, 1968), (Swisdak, 1975), (Swisdak, 1999) and (Kinney and Graham, 1985)). These values together with the computational results obtained from the simulations are shown in Figure 2 and Figure 3 for the peak overpressure and the peak reflected pressure respectively.



Injury predictions using pressure based injury criteria

From the peaks and durations of the pressure curves, injury criteria can be used to predict possible injuries that could occur at certain distances from the charge.

Figure 4 shows the regions within which injuries due to primary and secondary injuries caused by a M26 hand grenade may be expected. The grenade is positioned in the centre of the diagram. The orange circles indicate limits described for various levels of injury severity due to primary effects and the black circles indicate areas in which injuries caused by fragments could occur.



DISCUSSION OF EXPLOSIVE EVENT INJURY CRITERIA AND RESEARCH APPLICATIONS

This study focused on predicting primary injuries caused by the explosive charge, which, although it is understood that the fragments are the intended injury mechanism of the M26 hand grenade, provide insight into the use of current pressure based injury criteria to predict injuries in very close proximity to explosive charges.

It was found that the Bowen criterion predicted less severe injuries within a meter of the explosive charge than the CWVP criterion. The differences in severity are highlighted in Table 2.

Distance from charge	Bowen et. al. 1968 predicted injury level	CWVP predicted injury level
0.5 m	Less than 1% chance of lethality	Greater than 50% chance of lethality
1 m	Threshold for lung damage	Trace to moderate injury
15 m	No lung damage	No injury

The validity of the Bowen criterion for pressure profiles with positive-phase durations less than 0.2 ms or 0.4 ms for the CWVP criterion has yet to be determined. Further research is required to develop criteria suitable for this loading regime.

CONCLUSIONS AND RECOMMENDATIONS

The injuries described in the autopsy reports correlate well with the predictions made surrounding the primary and secondary effects of the explosion.

This study focused on the explosive charge contained in an M26 hand grenade. However, pressure based injury criteria can be applied to many different explosive event scenarios. A few of these include:

- The development and testing of body armour for humanitarian de-mining purposes
- Validation testing of armoured vehicles to assess the protection offered against landmines or improvised explosive devices
- The development and testing of bomb suits.

In many of these scenarios, the injury mechanisms are complex and may arise from a combination of primary, secondary, tertiary and/or miscellaneous wounding mechanisms. Developing a detailed understanding of these injury mechanisms and their interactions during explosive events is essential in enabling improved protection concepts to be developed.

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Unaccounted-for hand grenades have led to a number of deaths in the past 10 years. CSIR researchers investigate the injury mechanisms of grenades and other antipersonnel explosives.