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EXPLOSION OF IMPROVISED EXPLOSIVE DEVICE EFFECTS ON STRUCTURES

Abstract

This article deals with the matter of the protection from terrorist blasting, which has a high importance, since these kinds of activities occur almost on daily basis. It summarizes the main features of an explosion and the characteristics of one of the most common weapons of asymmetric warfare: the homemade or improvised explosive devices.

Az improvizált robbanószerkezetek elleni védekezés témakörének aktualitása napjainkban megkérdőjelezhetetlen, hiszen a robbantásos (terror) cselekmények szinte mindennapossá váltak a világban. Írásomban az aszimmetrikus hadviselés egyik leggyakoribb eszközei, a „házilagos készítésű" vagy improvizált robbanószerkezetek típusait és a robbanásának főbb jellemzőit összegzem.

Keywords: *Improvised Explosive Device, IED, explosion features, detonation, structures, terrorism ~ Improvizált robbanószerkezet, IED, robbanás jellemzői, detonáció, építmények, terrorizmus*

INTRODUCTION

According to NATO STANAG 3680 the Improvised Explosive Device (IED) is “a device placed or fabricated in an improvised manner incorporating destructive, lethal, noxious, pyrotechnic or incendiary chemicals and designed to destroy, incapacitate, harass or distract.” [1]

IED is an unconventional explosive weapon that can take any form and be activated in a variety of ways. It may be constructed out of any available material and may range in size from a box of matches to a large vehicle. The only limitations are the availability of resources, personal ingenuity, and the degree or extent of “know how” required for construction. They are usually fabricated from common materials, military or nonmilitary components. The IED may be static in a fix location and detonated as an observed device when the moving target (e.g. a military convoy) is in the ideal position and distance from the device; or it may be a mobile bomb delivered near to a static, fix target (building, military base).

PARTS AND FEATURES OF THE IED

The essential parts of an IED are the explosive charge, the detonator that initiates main charge and the triggering mechanism. Additional elements may be the power source, timer, fragments that increase lethal effect and a casing that also helps to camouflage the IED. [2]

The most common explosives used are military munitions, usually mortar, tank, or artillery rounds. Other IEDs have used military explosives, such as C4 and Semtex plastic explosives, trinitrotoluene (TNT) or commercial explosives, such as ammonium nitrate (fertilizer), and fuel oil (ANFO), Emulgit, Dynamite, etc. However, some IEDs may contain homemade explosives (HME) made of different chemical agents’ mixture. [3], [4]

All types of military and commercial blasting caps (electric, blasting, NONEL) can be used as initiator as well as detonators recovered from different military ordnance or landmines.

Figure 1. IED conceptual set-up [5]

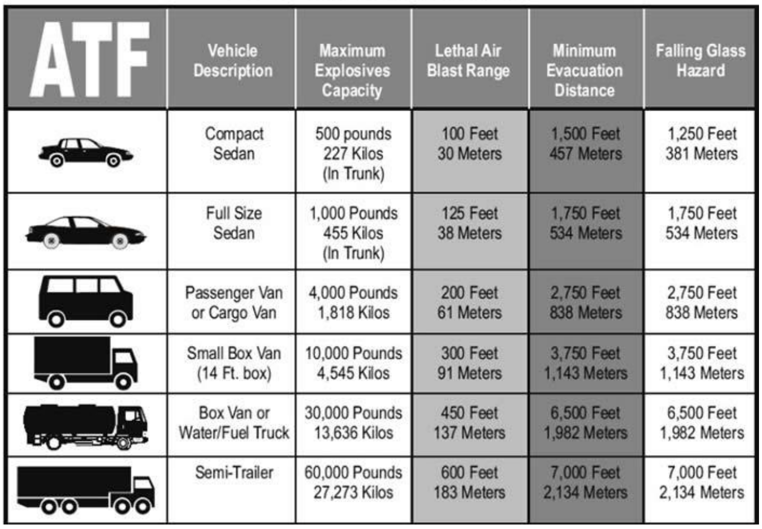
Power source of the electrically operated IED ranges from a simple battery cell to an accumulator, but in some cases even a solar cell may produce the necessary electric current.

Common hardware, such as ball bearings, bolts, nuts, or nails, can be used to enhance the fragmentation and cause more lethal or serious injuries in crowded places.

Propane tanks, fuel cans, and battery acid can also added to the device to propagate the blast and thermal effects of the IED.

It is always very important to hide the device for the successful attack; therefore terrorists pay high attention to camouflaging. Depends on dimensions of the IED, it may be covered in a harmless object such as a small tin, paper bag while a bigger device mainly used against buildings can be hidden in the boot of a car or truck (Figure 2).

BATF Explosive Standards



ATF	Vehicle Description	Maximum Explosives Capacity	Lethal Air Blast Range	Minimum Evacuation Distance	Falling Glass Hazard
	Compact Sedan	500 pounds 227 Kilos (In Trunk)	100 Feet 30 Meters	1,500 Feet 457 Meters	1,250 Feet 381 Meters
	Full Size Sedan	1,000 Pounds 455 Kilos (In Trunk)	125 Feet 38 Meters	1,750 Feet 534 Meters	1,750 Feet 534 Meters
	Passenger Van or Cargo Van	4,000 Pounds 1,818 Kilos	200 Feet 61 Meters	2,750 Feet 838 Meters	2,750 Feet 838 Meters
	Small Box Van (14 Ft. box)	10,000 Pounds 4,545 Kilos	300 Feet 91 Meters	3,750 Feet 1,143 Meters	3,750 Feet 1,143 Meters
	Box Van or Water/Fuel Truck	30,000 Pounds 13,636 Kilos	450 Feet 137 Meters	6,500 Feet 1,982 Meters	6,500 Feet 1,982 Meters
	Semi-Trailer	60,000 Pounds 27,273 Kilos	600 Feet 183 Meters	7,000 Feet 2,134 Meters	7,000 Feet 2,134 Meters

Figure 2. IEDs can hidden in vehicles [6]

The triggering mechanism of the IED may be victim operated, command operated or time delayed. Generally, the most common version is the mechanical trigger when the target gets into direct physical contact with it, push, pull, remove or release something that ignites the detonator. Time delayed constructions (clockwork, electric or chemical timers) independently operate the device after the pre-set time without any impact of the target. The command operated IEDs respond to a signal received via a hard wire or a radio frequency (wireless doorbells, car alarms, radio controlled toys, cellphones may be used).

A special version of command operated devices is the suicide born explosive device (SBIED), when the assailant sacrifices himself during the explosion. Smaller devices can be hidden in a vest or belt wrapped around the torso, the bigger ones those may be used against different structures in a car or truck (suicide vehicle born IED – SVBIED).

FEATURES OF THE IED EXPLOSION [7], [8]

The explosion of an IED is a very rapid release of stored energy. During this rapid exothermic chemical reaction the explosive material is transformed into very hot, dense and high-pressure gas which expands rapidly into the surrounding area forming a blast wave.

As a rough approximation, 1 kg of explosive produces about 1m^3 of gas. As this gas expands its act on the air surrounding the exploded IED and causes it to move and increase in pressure. The damage caused on structures by an IED explosion is produced by the passage of this compressed air in the blast wave which expands at high speed and reflected when meets objects. The difference between the blast wave pressure and the ambient air pressure is called the overpressure of the blast wave.

Because the blast wave expands outwards so rapidly, behind the blast wave is an area of low air pressure. This low-pressure area “sucks” the air along with it, causing a wind that initially follows the blast wave, thus creating a suction effect. As the blast wave continues outward, the relative pressure in front of, and behind the blast wave changes such that the direction of the wind can reverse direction, and for a short time it can blow in towards the point of the IED explosion (Figure 3).

Figure 3. Blast wave mechanism [9]

After detonation the atmospheric pressure almost instantaneously rises to a peak pressure that may be several orders of magnitude higher than ambient atmospheric pressure (Figure 4).

As the blast wave continues to expand away from the exploded IED its intensity diminishes and its expectable effect on the objects is also reduced. The pressure decays back to ambient pressure, then a negative pressure phase occurs. However, the negative phase is usually longer in duration than the positive phase, but its intensity is lower and causes less damage than the positive one.

The potential damage of a blast wave depends on both the shock front pressure rise and the impulse. Impulse is calculated as the area under a plot of blast pressure versus time (pressure-time relation plot), and it characterizes the duration of the dynamic loading. Instead of decaying exponentially with time as blast waves do, the decay may be approximated as linear. The duration of the linearly decaying positive phase pressure pulse may be calculated as twice the impulse divided by the magnitude of the peak pressure.

Whereas the magnitude of the shock wave's peak pressure is analogous to the punch, the magnitude of the shock wave's impulse may be analogous to a push.

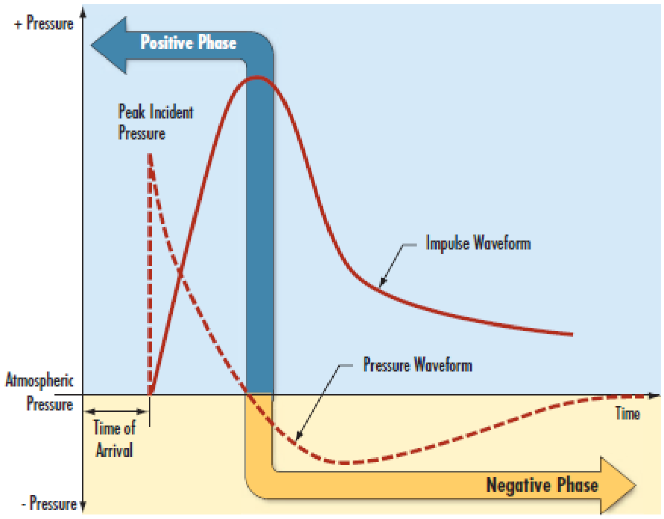


Figure 4. Pressure-time relation and blast impulse waveform [7]

Therefore, the magnitude of the peak pressure alone is inadequate to describe the intensity of the blast loading: both the pressure and impulse (or duration time) are required to define it.

EFFECTS OF THE EXPLOSION

The energy output of explosives can be related by TNT equivalency. This equivalency is usually considered to be the relative pressure achieved by the explosive compared to what TNT can achieve. A constructed object will suffer damage when the impulse and the pressure both exceed damage threshold values. A version of damage threshold pressures and impulses corresponding to various categories of structural damage are listed below (Figure 5).

Structure/object	Pressure (psig)	Impulse (psi-msec)
Plate Glass Windows:		
20 ft^2 pane, 3/16″ thick	0.3–0.6	–
10 ft^2 pane, 3/16″ thick	0.6–1.0	–
10 ft^2 pane, 1/4″ thick	1.1–1.6	–
Wood Roof Joist, 13 ft Span	0.5	–
Brick Wall – Minor Damage	0.7	16
Brick Wall – Major Damage	2.0	43
Wood Stud Wall, 7.5 ft high	1.0	1
Sheet Metal Panel Buckling	1.1–1.8	–
Wood Siding Failure	1.1–1.8	–
Cinder Block Wall Failure	1.8–2.9	–
Wood Frame Building Collapse	3.0–4.5	36
Oil Storage Tank Rupture	3.0–4.5	–
Structural Steel Building	4.5–7.3	–
Reinforced Concrete Wall	6.0–9.0	–
Total Destruction of Most Bldgs	10–12	–
Overturning of 10 ft high truck	0.3	110

Figure 5. Blast damage pressures and impulses [10]

According to results of blasting tests it can be declared that approximations of incident overpressures may cause different damages in buildings as follows (measured in psi):

- glass window breakage 0,15–0,22
- minor damage to building 0,5–1,1
- panel of sheet metal buckled 1,1,–1,8
- failure of concrete block wall 1,8–2,9
- serious damage to steel framed building 4–7
- severe damage to reinforced concrete structure 6–9
- probable total destruction of most building 10–12

Blast loads vary in time and space over the exposed surface of the building (Figure 6), depending on the distance and location of the IED detonation in relation to the building's shape.

Figure 6. Blast loads on a building frontage [11]

When the incident pressure wave strikes an immovable surface (a structure) that is not parallel to the direction of the wave's travel, it is reflected and reinforced. Therefor at the same distance from the explosion the reflected pressure is always greater than the incident pressure, and varies with the incident angle. This reflected pressure actually causes the damage to the building. A very high reflected pressure may punch a hole in a wall or cause a column to fail, while a low reflected pressure will try to push over the whole building. The worst case is when the direction of travel for the blast wave is perpendicular to the surface of the structure and the incident pressure is very-very high (Figure 7).

The extent and severity of damage and injuries that result from an IED detonation may vary widely depending on specific details of construction and materials. Although some of the specific details are not known, the overall level of damage that may be expected in response to an explosion can be calculated. Based on experiences, the brittle materials (like glass) respond to peak incident pressure and are less affected by impulse; that is why a high explosive with high incident pressure easily damages glass. On the other hand, the ductile materials (like most building structures) respond more to impulse (the total push) rather than peak incident pressure (the maximum hit); that is why a low explosive with a large impulse that pushes for a longer time causes more damage to buildings.

As it was mentioned above, the reflected pressure causes the main damage. The air blast strikes the front wall and the weakest component will fail first: it is usually the window. Sometimes unreinforced masonry walls can be weaker than windows, especially if they are non-load bearing. If the IED is close enough, these walls can breach and one or more columns can fail in addition to the windows.

After the blast wave enters inside, it is trapped while more and more air enters the building, further increasing the pressure. Any building component that traps the blast wave can expect damage, based upon how it is constructed and attached.

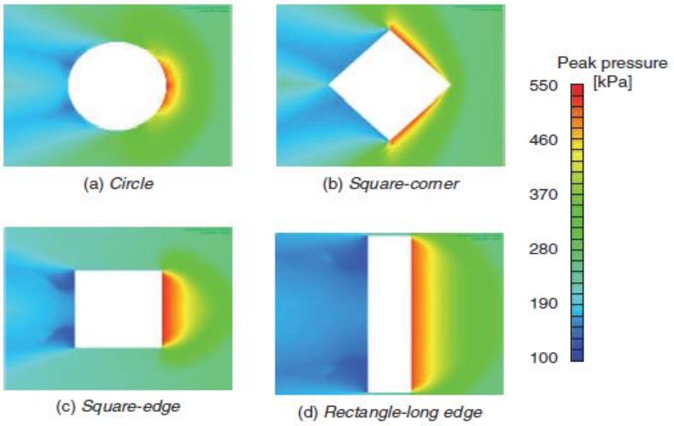


Figure 7. Cross sections peak pressures [8]

Structural components like flooring and shear walls will move in directions for which they were not designed. Based upon the reflection angle, one can expect the lower floors to receive the greatest damage. Big concrete chunks rain down or the whole floor gives way. After the blast wave engulfed and passed the building, the building's far side (opposite side to the IED explosion) receives increased pressure as a slight vacuum forms and the ambient air rushes back in to achieve equilibrium. Reflections of the blast wave off other structures behind this one can also increase the pressure impinging the far side of the building.

The computer-assisted evaluations above are all based on the quality and quantity of the explosive, the size of the explosion, the distance from the IED, the shape and other assumptions about the construction of the building. In addition to the factors above, there is a truth to accept: stand-off distance is your best friend. The larger the distance between IED and the structure, the smaller the damage the building suffered.

SUMMARY

One of the most popular weapons of the asymmetric warfare is the homemade or improvised explosive device. It is very easy and cheap to construct these devices, manuals are available in Internet, and the components can be purchased in a hardware shop. IED's tactical effect emerges in the large number of victims, the possible grandest damage on structures but due to the media, public interest and deterrence, they might have strategic effects.

These pages only shortly highlighted the main features of an IED and the general characteristics of an IED explosion, primarily focused on the effects on constructed infrastructure, not on persons (fragmentation, heat, etc.).

Compared to other hazards an IED explosion has a few distinguishing features: its intensity of the pressures acting on a building or construction can be several orders of magnitude greater than the intensities associated with other hazards. Most construction materials will sustain major damage or failure at the very high peak pressure level. Damages on the side of a building facing an IED may be significantly more severe than on the opposite side. (In a densely built area, reflections off surrounding buildings can affect these damage patterns.)

The duration of the blast event is significantly shorter compared with the duration of other dynamic loads (e.g. wind pressure), therefor the reaction of structures also differ. Generally, buildings cannot resist the extremely short and high pressure load.

There are several documents, manuals and articles dealing with criteria and standards of permanent or temporary (military) constructions. [12], [13], [14], [15], [16]

These documents define the design threat, protection level and residual risk of structures and give a detailed planning guide for designing, developing and testing them. Effective protection or even more the prevention of IED events are the all of us interest.

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