BLAST THREAT TO CRITICAL AND MILITARY INFRASTRUCTURE

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Abstract

Blast attacks to public structures and critical or military infrastructure present threats that must be taken seriously. In modern asymmetric conflicts, force protection engineering mainly deals with protection against explosions caused by IED's and the mitigation of blast effects. Protective measures are based on practical experience with blast effects on structures and personnel, or on modern methods such as simulations. Different methods can be used to assess and analyze possible effects of blast attacks on constructions. Simulations can be used to predict the effects of explosions and can help to discover adequate protection measures. The aim of the article is to briefly present the use of AUTODYN software as a possible way of predicting the effect of blast attack. Simulations in this field are applicable not only in the military but in critical infra-structure protection too. The protection of critical infrastructure against a terrorist attack is a one of the most challenging issue nowadays. Government experts face problems with appropriate countermeasures in the uncertain environment of unidentified IED threats.

Introduction

Terrorist attacks by explosives means have a long history. But in recent years, the explosive devices have become the weapon of choice for the majority of terrorist attacks. Such factors as the accessibility of information on the construction of explosive devices, relative ease of manufacturing, mobility and portability, in connection with significant property damage and injuries, are the reasons for the significant increase in bomb attacks all over the world. In most of the cases, structural damage and the glass hazard have been major contributors to death and injury in the attacked buildings. As a target of such an attack a military object or public infrastructure can be chosen.

One of the biggest threats to both military installations and public objects is an attack by explosive means. Such factors as the accessibility of information on the construction of explosive devices, the relative ease of manufacturing, mobility and portability, coupled with significant property damage and injuries, are responsible for the significant increase in bomb attacks on public structures all over the world.

The most well known attacks by explosives are the bombing of the World Trade Centre in New York City in February 1993, the devastating attack against the Alfred P. Murrah Federal Building in Oklahoma City in April 1995 (see fig. 1a) and the recent collapse of both WTC Towers. There are a lot of lesser attacks all over the world that have underscored the attractiveness and vulnerability of urban areas and civilian buildings as terrorist targets. These attacks have also demonstrated that modern terrorism should not be regarded as something that could happen elsewhere, but rather that there is a lot of examples of bomb attacks on public infrastructure in recent years.

- The London bombings happened as a series of coordinated suicide attacks on London's public transport system during the morning rush hour of 7 July 2005. Fifty-six people, including the four suicide bombers, were killed in the attacks and about 700 were injured. Three bombs based on home-made organic peroxide-based devices exploded on three London Underground trains, a fourth exploded on a double-decker bus.
- Suicide bombings in the center of Moscow carried out during the morning rush hour of 29 March 2010, at two stations of the Moscow Metro, with roughly 40 minutes of interval between them. At least 40 people were killed, and over 100 injured. Two bombs were used with a force of up to 4 kg and 2 kg of TNT. Both bombs were packed with metal nuts, bolts and screws, to increase the destructive impact of the blasts.

- The Oslo blast attack in the Oslo's central government district on 22 July 2011. The explosion damaged a government building (see Fig. 1b) and blew out windows over more than a half-mile radius, filling the area with smoke and littering it with shards of metal. Seven people were killed and scores injured. The bomb was made from a mixture of fertilizer and fuel oil and placed in the back of a car parked in front of the government building.
- The blast in the Belarus capital Minsk on 11 October 2011. The blast occurred on a platform at one of Minsk's busiest underground station in evening rush hour. The explosive device, which had been packed with metal balls and had a strength equivalent to 5–7 kg of TNT, was apparently left under a platform bench. About 300 people were present when it exploded as a train came into the station. Twelve people were killed and 126 were injured.

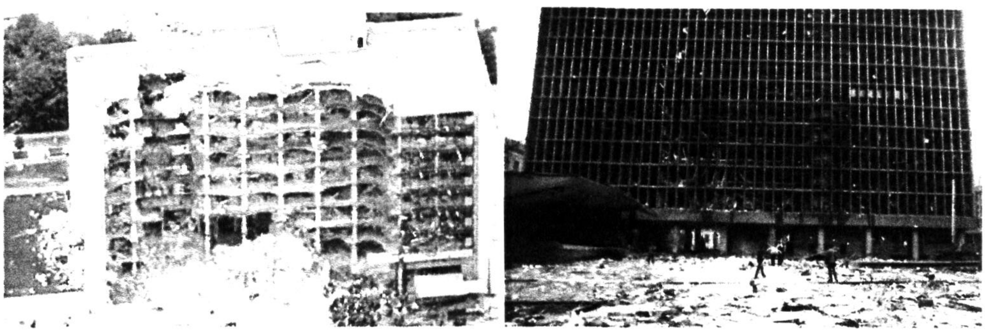

Figure 1a, 1b. 1a: Alfred P. Murrah Federal Building in Oklahoma City; 1b: Government buildings shattered in Oslo

Threats

One of the biggest threats to both military installations and public objects is an attack by explosive means. The effect of the attack particularly depends on the amount and kind of explosives used in the explosion. An attack by explosives can be generally done in the shape of a small bomb or a vehicle bomb.

The high effectiveness of an IED is based on the simplicity of production, availability of resources and the rapid spread of relevant information by the internet. A similar situation can be found regarding non-military and public areas where a lot of different possible targets like public transport means or infrastructure systems exist. These targets, because of the lesser level of protection against attack with explosives, are more vulnerable.

The effect of an attack specifically depends on the amount and kind of explosives used in the explosion. There are a lot of explosives that can be utilized for IEDs production. Depending on sources and availability either military or commercial explosives can be used. Another possibility is the utilization of homemade explosives mostly based on perchlorates, hydrogen peroxide mixtures (triacetone triperoxide – TATP) or a mixture of ammonium nitrate fertilizer and fuel (ANFO). Ingredients for homemade explosives are easily obtained on the open market and that's why they are frequently used to produce vehicle bombs.

Explosives

There are a lot of explosives that can be utilized for small bomb or vehicle bomb production. Explosives are generally categorized as high-order explosives (HEs) or low-order explosives (LEs). HEs produce a defining supersonic over-pressurization shock wave. Examples of HEs include TNT, C-4, Semtex and nitro-glycerine. LEs create a subsonic explosion and lack HE's over-pressurization wave. Black-powder or gunpowder is an example of such an LE.

Depending on sources and availability either military or commercial explosives can be used. Another possibility is the utilization of homemade explosives mostly based on perchlorates, hydrogen peroxide mixtures (triacetone triperoxide – TATP) or a mixture of ammonium nitrate fertilizer and fuel (ANFO). Ingredients for homemade explosives are easily obtained on the open market and that's why they are frequently used to produce vehicle bombs.

Attacks by explosives can be generally done in the shape of a small bomb or a vehicle bomb.

Small bombs can be delivered as a mail bomb; hand delivered in a briefcase or rucksack or can be worn by a person such as suicide bomber or can be placed such as with a pipe bomb, for example. A suicide bomb can be contained in a vest, belt, or clothing that is specifically modified to carry this material concealed. A small bomb can cause the greatest damage and casualties when brought into the vulnerable, unsecured areas of a building interior, such as the building lobby, mail room, and retail space or underground stations. Recent events around the world make it clear that there is an increased likelihood that bombs will be delivered by persons who are willing to sacrifice their own lives. Hand carried bombs and suicide bombs are typically in the order of two to five kilograms of trinitrotoluene (TNT) or equivalent. However, larger charge weights, in the 5 to 50 kilograms TNT equivalent range, can be readily carried in rolling cases. Mail and pipe bombs are typically less than five kilograms of TNT equivalent, ordinarily to two kilograms.

Vehicle bombs (VBIED) are able to deliver a sufficiently large quantity of explosives to cause potentially devastating structural damage and that's why they present the biggest threats to Military or critical infrastructure components. They present one of the biggest threats to military installations such as a Forward Operating Base (FOB) or a Main Operating Base (MOB) and they can result in a greater effect on the target. The explosion within or immediately nearby a military installation can cause huge damage to constructions, the collapse of protective walls, projections of fragments and casualties that can occur as the result of the direct blast effects. Subsequent damage as well as casualties can be caused by the collapsing of constructions or secondary fragments. The vehicle bomb's size can be calculated on the basis of the loading capacity of a vehicle.

For practical reasons representative bombs are used and their explosive capacity are given in table 1 for civilian use and in table for military use.

Representative bomb		**Explosive capacity [kg]**
Small bomb	Mail or pipe bombs	< 2
	Hand carried bombs and suicide bombs	2–5
	Rolling cases bombs	5–50
Vehicle bomb	Motorbike	50
	Passenger vehicle	400
	Van	1 500
	Medium truck	4 000
	Box van, fuel truck	13 000
	Semi trailer	27 000

Table 1. Explosive capacity of representative bombs [1], [2]

	A Small / medium calibre projectiles	B Shoulder launched weapons / Rifle grenades	C Battlefield rockets, Artillery and Mortars	D Small / Personnel-borne IEDs	E VBIEDs
5	Automatic cannon 30 mm APDS	Advanced ASM Anti Structure Munition	155 mm artillery 122 mm rocket	Bag / Suitcase 20 kg TNT	Heavy truck / similar > 4000 kg TNT
4	Heavy machine gun 12.7 – 14.5 mm AP	Anti-tank Shaped charge	120 mm mortar 107 mm rocket	Body-borne device 9 kg TNT, fragments	Medium truck 4000 kg TNT
3	Assault / Sniper rifle 7.62 mm AP WC	Anti-personnel Thermobaric charge < 2.5 kg Conventional	82 mm mortar	Large briefcase 9 kg TNT	Van 1500 kg TNT
2	Assault rifle 5.56 – 7.62 mm AP	40 mm Rifle grenade Shaped charge	60 mm mortar	Package 1.5 kg TNT	Passenger vehicle 400 kg TNT
1	Assault rifle 5.56 – 7.62 mm Ball	(Reserved)	Hand grenade	Letter bomb 0.125 kg TNT	Motorbike 50 kg TNT

Table 2. Existing Design Threat Level Table according to STANAG 2280.

Explosion effects

When an explosive charge is detonated in the air or on/in the ground, there are several primary effects (see Fig. 2) that should be considered: air blast, fragmentation, crater ejecta, ground shock, and thermal effects (heat).

1. *Air blast* is the basic effect from any detonation event with uncased or cased explosives. The elements of air blast that will be observed at the exposed site are the peak incident overpressure, the blast impulse, and the dynamic pressure (air flow).
2. *Fragmentation* is generally considered to be of two types. Depending on their origin, fragments are referred to as primary or secondary fragments.
3. *Crater ejecta* can also result from explosive events and can cause the same effect as secondary fragments.
4. *Ground Shock* is the coupling of energy into the ground as a result of a detonation or explosion.
5. *Thermal effects (heat)* are usually associated with the fireball that is produced by an explosive event.

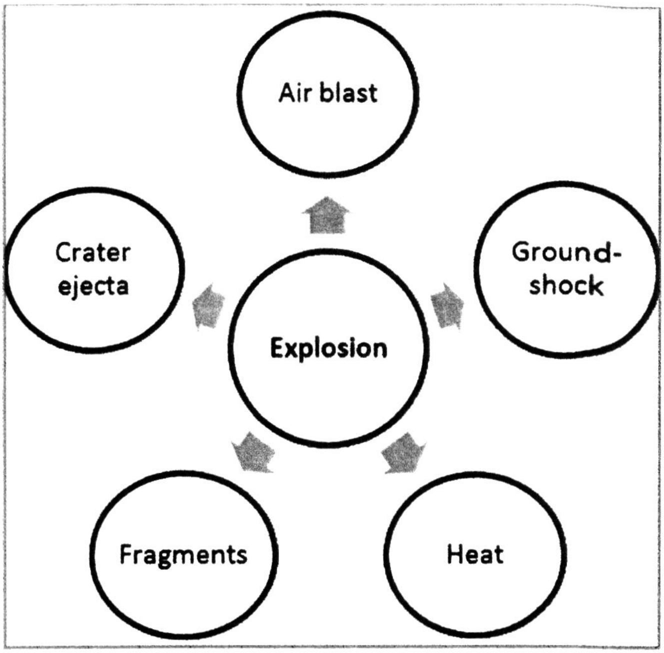

Figure 2. Explosion effects

The most structural damage to a construction from an external explosion is caused by the response to air blast, fragment impact, and ground shock.

The extent and severity of damage and injuries in the result of an explosive attack can be assumed on the base of the amount of explosive, distance from the explosion site, and assumptions about the construction.

Damage due to the air blast may be divided into direct air blast effects and progressive collapse.

Direct air blast effects are caused by the high-intensity pressures of the air blast in the proximity of the explosion site. These may induce localized failure of exterior walls, windows, roof systems, floor systems, and columns. Progressive collapse is referred to as the spread of an initial local failure from element to element, eventually resulting in a disproportionate extent of collapse relative to the zone of initial damage. Localized damage due to direct air-blast effects may or may not progress, depending on the design and construction of the building. To cause a progressive collapse, the bomb must be in close proximity to a critical load-bearing element. Progressive collapse can propagate vertically, upward or downward, from the source of the explosion, and it can propagate laterally from bay to bay as well.

The pressure that an explosion affects on construction surfaces may be several orders of magnitude greater than the loads for which the construction is designed. The shock wave also acts in directions that the construction may not have been designed for, such as upward pressure on the floor system.

Assessment of blast effects

Different methods can be used to analyze and assess possible subsequent effects of a blast attack to any target. The simplest method is empirical calculation with basic results; the most sophisticated method is numerical simulation.

The crucial problem of each calculation or simulation is the number of suitable evaluation criteria. It is possible to use a numerical simulation of damages due to air blast or impact on structural fist members but concerning the whole structure the simulation is restricted by computer and software limitations – a 3D simulation of steel or concrete structural member hit by pressure wave costs millions, has many equations and takes several days or weeks for a solution for 100–500 milliseconds of effects.

To calculate basic data for assessing a structure, three main methods can be used:

- Empirical calculation based on scaled distance from the TNT charge and empirical formulae of overpressure, pressure impulse and the time of arrival and time of duration;
- A semi-empirical calculation based on the same formulae as previously but for simple geometries, some software tools can be used for calculation (e.g. ConWep and BlastX from U.S. Army Corps of Engineers, Protective Design Centre, or Mathcad handbook DynamAssist);

- Numerical method based on explicit solution of motion equations, appropriate solver is often part of complex simulation software and can solve complex geometry and loading conditions.

Empirical calculations of the blast effect are mainly focused on the spreading of pressure a wave in the air and the calculation of overpressure for both types of burst – air burst and surface burst (see Fig. 3). Numerical methods based mainly on Euler or Lagrange solver allow us to compute a complex simulation where pressure, velocities and deformations are basic output data at each point of simulation and damage levels, strains and other structural characteristics are available too.

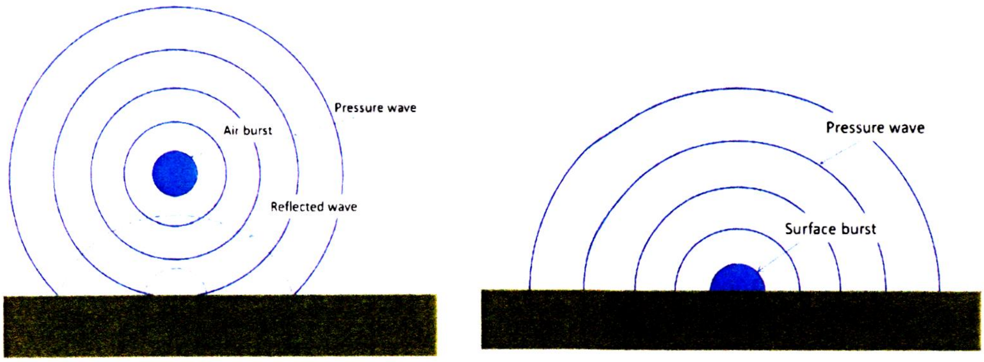

Figure 3a, 3b. 3a: Spherical free air burst, 3b: Hemispherical surface burst

Regarding VBIEDs, as a result of applied protective structures and safety measures VBIEDs cannot get into the interior of a military installation and therefore the main effect of the explosion will be an intensive air blast wave impacted on perimeter and entrance structures and some of the characteristic parameters of the wave can be calculated. By comparison with the following table we can estimate the range of damage or injury.

Damage Object	Occasional	Minor damage	Medium damage	Heavy damage	Destruction
	Overpressure Δp [kPa]				
glass, large window	0.2	–	–	–	–
glass, typical window	–	1.1	–	–	3.5 – 7.0
concrete wall, 20–30 cm	–	–	–	14–21	–
brick wall – completely demolished	–	–	–	56.3	70.3
brick wall, 20–30 cm – fail by flexure	–	–	–	–	56.3
brick wall, 45 cm – completely demolished	–	–	–	–	91.4
steel building	–	9.1	14.0	17.6	21.1
wooden building	–	–	12.0	17.0	28.0
industrial building	–	–	28.0	–	–

Table 3. Damage criteria for structures or components due to overpressure – examples [kPa]

Empirical calculation

Most structural damage from an external explosion is caused by response to the airblast. In general, the effect of the blast specifically depends on the standoff and on the amount of energy released by a detonation represented by the amount of explosives. The standoff is the distance measured from the center of gravity of the charge to the component of interest. The bomb size depends on the delivery capacity of the attackers and for basic calculation representative bombs are used.

To calculate the essential airblast parameters of the representative bombs, particularly VBIEDs, and use these calculated parameters for the assessment of the airblast effects on protective structures and either to set down safety distances or to design adequate force protection measures, simple relations can be applied. For this calculation symbols given in Table 4 are used.

Symbol	Dimension	description
E^d	$J \cdot kg^{-1}$	Specific detonation energy
^{Ed}TNT	$J \cdot kg^{-1}$	Specific detonation energy of TNT
NEQTNT	–	TNT equivalent factor
P_a	MPa	Atmospheric pressure
P_r	MPa	Peak reflected overpressure
P_{SO}	MPa	Side-on overpressure
q_0	MPa	Dynamic pressure
Q_{TNT}	kg	TNT equivalent charge
Z	$m \cdot kg^{-1/3}$	Scaled distance

Table. 4: Symbols used.

In general, the relations used to calculate airblast parameters are based on the use of pure TNT charges. For calculations related to other explosives it is necessary to use the corresponding TNT equivalent charge calculated on the basis of TNT equivalent factors (see equation 1 and 2), given in Table 5. The estimation of the airblast parameters at different distances in relations to different charge masses can be given by the scaled distance Z (see equation 3) that represents correlations between a particular explosion and a standard charge of the same explosive.

	Detonation velocity	**Bulk density**	**TNT equivalent factor – NEQTNT**
Explosive	$/m \cdot s^{-1}/$	/kg·m-3/	–
ANFO	3 200	0.84	0.82
Composition B (TNT/RDX 40/60)	7 470	1.60	1.11
Composition C4	8 040	1.63	1.37
Pentolite (TNT/PETN 50/50)	7 460	1.66	1.42

Table. 5: Representative explosives and their TNT equivalent factors

TNT equivalent factor – NEQ_{TNT}

$$NEQ_{TNT} = \frac{E^{d}}{E^{d}_{TNT}} \tag{1}$$

TNT equivalent charge – Q_{TNT}

$$Q_{TNT} = Q \cdot NEQ_{TNT} \tag{2}$$

Hopkinson-Cranz scaling law for scaled distance – Z of a blast: [2]

$$Z = \frac{R}{\sqrt[3]{Q_{TNT}}} \tag{3}$$

The other basic characteristics of blast wave such as a side-on overpressure, shock front velocity, incident pressure, and incident impulse can be calculated according to equations in [2] and [3]

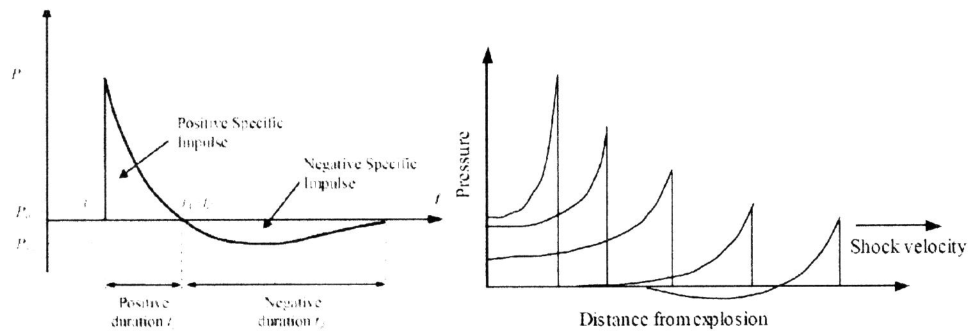

Figure 4a, 4b. 4a: Dependency of overpressure at given distance on time of duration after explosion; 4b: Chart of maximum pressure at distance from explosion

The following paragraphs show some examples of blast or impact simulations with different demands on hardware and computational time solved with AUTODYN software. These demands often rely on solver type, duration of incident and the possibility to simplify solution.

Numerical simulation

Numerical simulations are mainly based on an explicit solution of motion equations; an appropriate solver is often part of complex simulation software and can solve complex geometry and loading conditions. Numerical methods based mainly on the Euler or Lagrange solver allow us to compute complex simulations where pressure, velocities and deformations are the basic output data at each point of the simulation and damage levels, strains and other structural characteristics are available too.

Based on knowledge of blasting action and convenient software, the effect of a blast attack can be simulated to predict outgrowth of blast to the construction. An explicit solver such as ANSYS/AUTODYN can be successfully used for the simulation. The significant advantage of AUTODYN is a library of materials suitable for the simulation of explosions, blast effects, and impacts with appropriate material constants filled. For some material models an HPC and parallel computing on shared and distributed memory systems can be used.

Modern software tools like AUTODYN can help experts to properly assess threats in asymmetric conflicts at a reasonable cost. Due to the complex nature of the high velocity inter-action between bodies or blast wave spreading as well as the physical phenomena being analyzed, it is extremely important for the user of the tools mentioned to have a good understanding of the underlying assumptions and limitations of the models. ANSYS AUTODYN has been used in a vast array of projects including those concerning nonlinear phenomena. It is also possible to use it effectively for building protection measures and insurance risk assessments for blast effects in military bases.

Euler solver, 2D and 3D simulation of blast wave

Euler solver used in AUTODYN is very effective for the simulation of a blast pressure wave spreading in the air or the simulation of blast effect on a structure when a charge detonates some distance from the object of interest. The Euler solver uses the computational mesh that is fixed in the space of i-j (2D) resp. i-j-k (3D) mesh (see Fig. 5). The mesh is not deforming, it remains the same in time. Materials are flowing across the mesh and therefore it is necessary to evaluate the transport terms of the mass, energy, and momentum at each computational step.

Special formulation of this solver was developed for the simulation of the pressure wave after a blast in the air; this is most effective solver for the calculation of a reflected pressure wave inside an urban area or inside buildings (see Fig. 6).

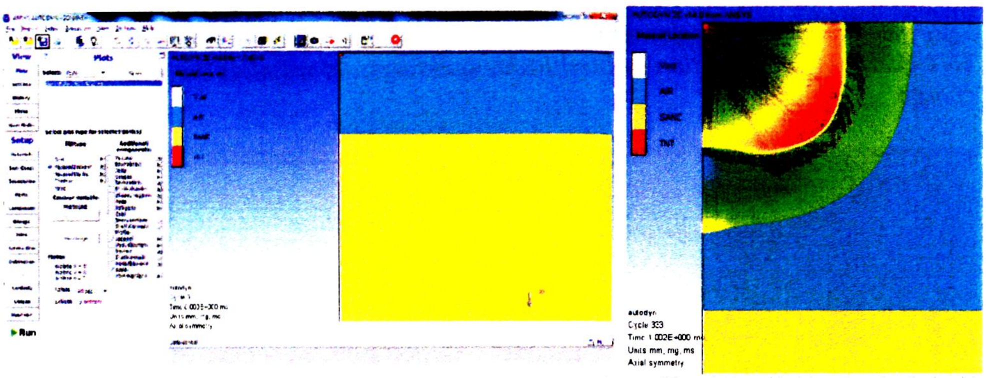

Figure 5a, 5b. 5a: 2D axis symmetry simulation of spherical free air burst – initial conditions in AUTODYN; 5b: Detail of "flowing" materials through 2D i-j mesh, 1 ms after detonation of TNT charge.

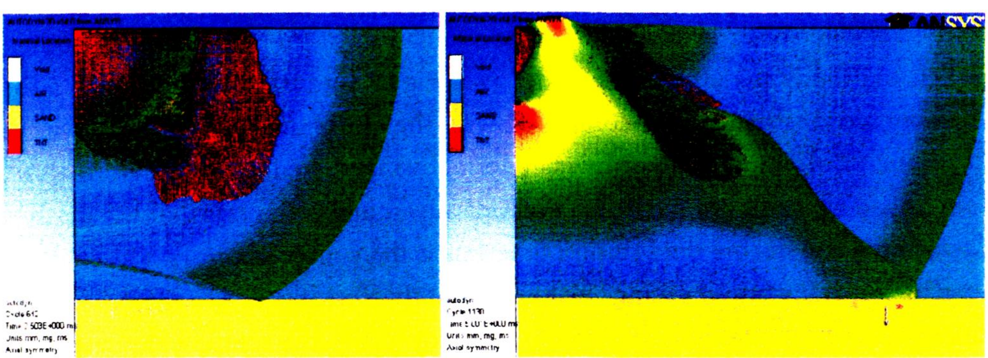

Figure 5c, 5d. 5c: Beginning of reflection of pressure wave, 2.5 ms after detonation of TNT charge, 5d: Initialization of "triple point" of reflected wave, 5 ms after detonation of TNT charge.

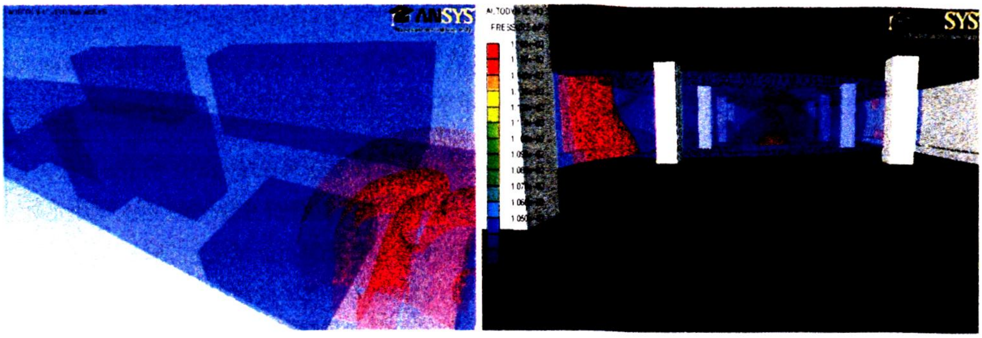

Figure 6a, 6b. 6a: Simulation of blast inside an urban area, 20 ms after detonation of TNT charge, 6b: Simulation of blast inside buildings, 50 ms after detonation of TNT charge

These simulations conducted at our department allow us to assess the consequences of a blast with criteria according to Table 3. The most important parameter is a pressure level; which can be measured during simulation at any point through gauges and later evaluated as a time dependency chart.

Lagrange solver, blast behind concrete protective wall

The Lagrange solver is effective for the simulation of the interaction of bodies, when one body penetrates the other (see Fig. 7 and 8). This solver uses the computational mesh that is connected with the continuum, in the same way as a classic FEM. Thus, it deforms in time following the continuum deformation. No transport terms are needed, a great disadvantage is the fact that the mesh is deforming and during the solution time this is the source of errors. The solution can be "rezoning or remeshing" technique but this introduces a new more regular mesh at certain times and therefore it introduces into the solution similar errors as in the transport terms above.

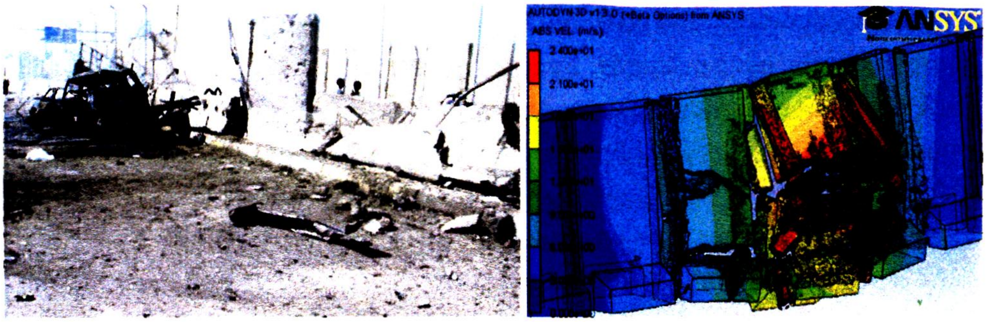

Figure 7a, 7b. 7a: Damaged protective wall after VBIED atack, 7b: Simulation of blast behind T-Walls, 25 ms after detonation of TNT charge

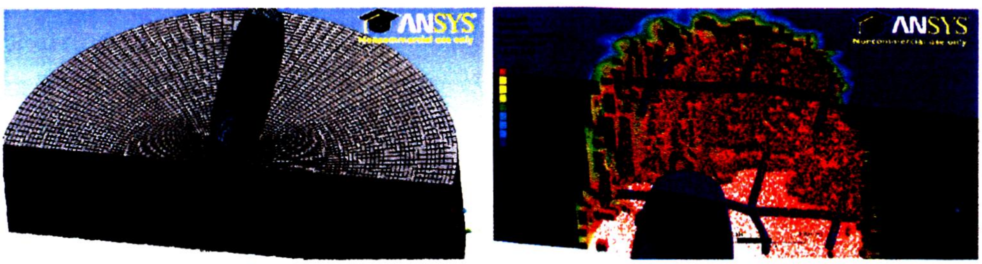

Figure 8a, 8b. 8a: Simulation of the penetration of projectile into RC slab – Lagrangian mesh, 8b: Simulation of the penetration of projectile into RC slab – damages after 10ms

These kinds of simulations allow us to assess for example the interaction between bodies after an explosion or damage level inside bodies subjected to a blast wave. The most important parameters are impact velocity, damage level and strain of materials; this result can be animated and this gives us a good view into the mechanism of this incident.

Entry Control Point of Military Base

One of the biggest threats to military installations such as a Forward Operating Base (FOB) or a Main Operating Base (MOB) is an attack by vehicle bombs (VBIEDs). The entry Control Point (ECP) is one of the most important parts of the perimeter, which is surrounds the military base. Every person and car entering the base has to go through this point. For this reason there is high requirement to position it properly and also built it from appropriate materials. The failure to comply with the main principles leads to a massive loss of life, weapons and other stuff. A VBIED explosion within or immediately nearby a military installation can cause huge damage to constructions: the collapse of protective walls; the emission of fragments causing harm as well as the casualties that can occur as a direct result of the blast. Subsequent damage as well as casualties can be caused by collapsed constructions or secondary fragments.

As a result of applied protective structures and safety measures VBIEDs cannot get to the interior of a military installation and therefore the main effect of the explosion will be an intensive air blast wave impacted on the perimeter and entrance structures. In the case of a VBIED attack it is assumed that there will be used a cube shaped explosive charge and it will be placed in a close proximity to the ground. As a result, the air blast wave will spread as a hemispherical air blast wave and then some of the characteristic parameters of the wave can be calculated. Based on these preconditions a numerical simulation can be done to predict the effects of an attack or to design adequate force protection measures.

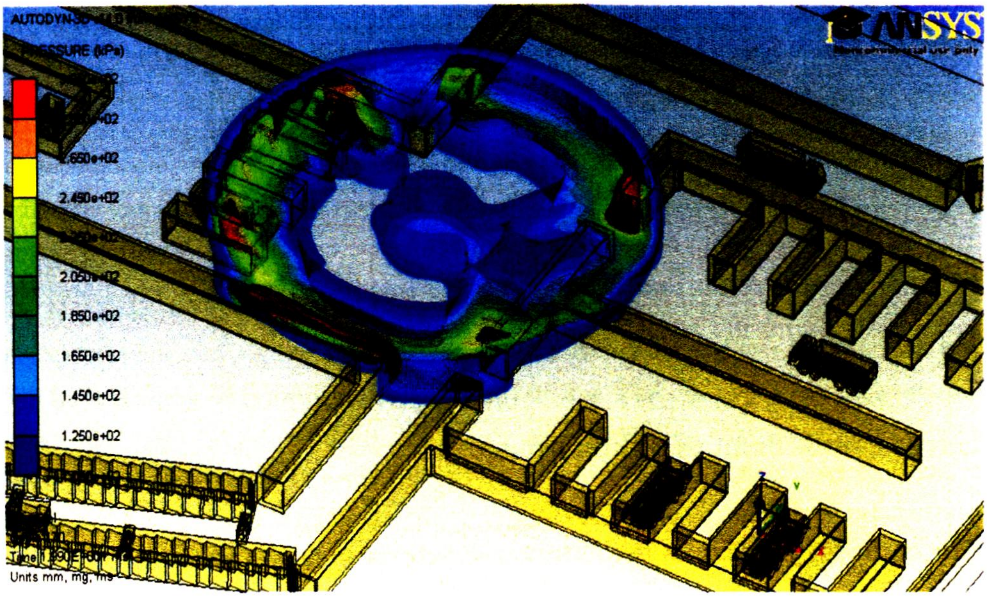

Figure 9. The explosion of a 1000 kg of TNT between control zone and parking, time – 20 ms

Despite all these barriers the enemies can overcome the ECP and initiate the VBIED. With the blast of such a big quantity of explosives a large blast wave formed which crucially destroys humans and material at the base. The knowledge of the blast wave spreading and its size are important for a better arrangement of the ECP and also to improve the protection of the base. For this reason there is a need to know how the blast wave will spread at the entrance.

Critical infrastructure in transportation

One of the possible objects that can be attacked by terrorists is the public transport system, primarily a metro (underground railway). Terrorists can carry out any attack in a metro station by bringing in a charge, hidden in personal luggage or belted on the body under a coat. They can use several charges in one station, but simultaneous detonation or detonation with controlled initiation is unlikely in this instance. Assuming a brought in charge, an attack will be against people with a significant pressure wave and fragmentation effect. Damage to the station will not lead to collapse of the whole structure, but damages to equipment and auxiliary and service structures could be significant.

An attack aimed at the collapse of the whole station structure is less probable, it needs more than several hundred of kilograms of explosives (a vehicle bomb is assumed). Under-surface stations are relatively secure against this kind of attack. Surface stations are similar targets to other public buildings, but less attractive.

It is supposed that in a similar situation as in the Moscow metro, but rather a suicide attack will be conducted on a platform just before the train enters the station, when the platform is full of people. An explosion is in the middle of the platform between the train and the wall, its height is 1 m. It is assumed to be a belt charge of 10kg TNT. The simulation was conducted in two steps.

Figure 10a. Metro station

Firstly, the detonation and pressure wave formation was modeled. Secondly, the pressure wave was remapped on to a metro platform and the spread of pressure wave was calculated.

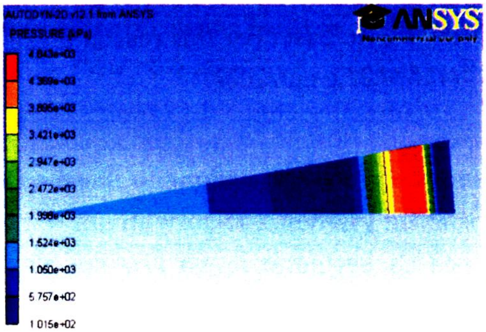

Figure 10b. Explosion of 10 kg of TNT

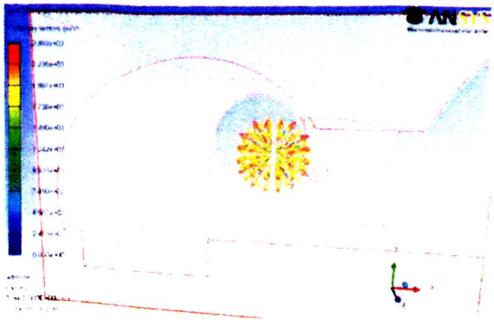

Figure 10c. Pressure wave remapped on to platform

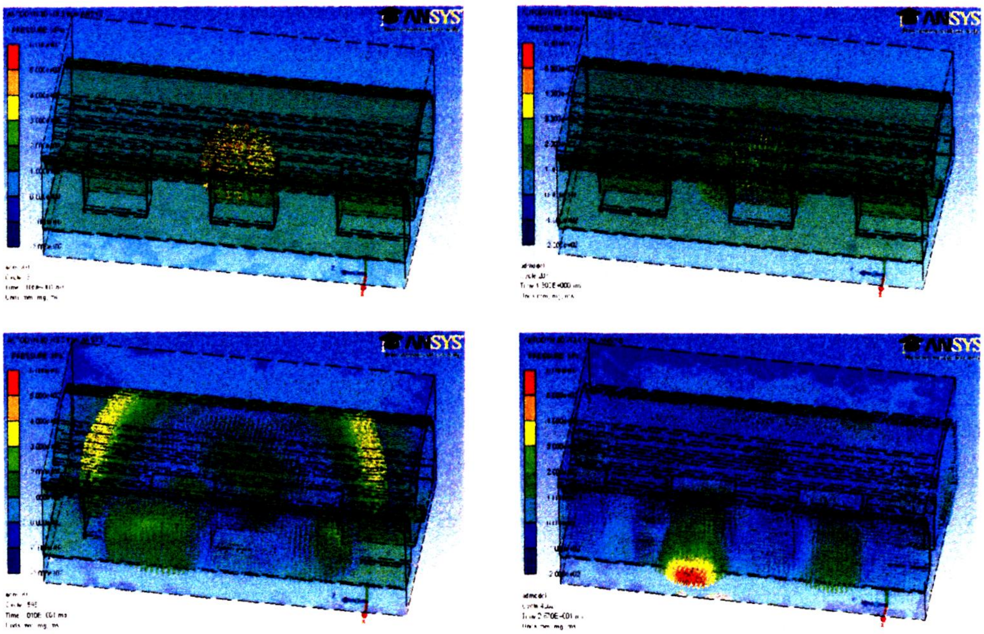

Figure 10d. Pressure wave calculation

Conclusion

Explosive means, mostly VBIEDs, present very effective and relatively easily available means of attacking public installations. They are increasingly used because of their simplicity and availability. Many protective structures are used on the basic of their actual efficiency but some of them can pose a threat to the protected objects. Simple calculation of the airblast parameters concerning VBIEDs can be helpful to engineers to plan the application of proved protective structures. To design new or verify currently used protective structures the numerical simulation should be applied to get results which correspond to the actual threat.

Based on the knowledge of blasting actions and convenient software the effects of a blast attack can be simulated in order to predict blast outgrowth to constructions. Modern software tools like AUTODYN can help experts to properly assess threats in asymmetric conflicts at reasonable cost. Due to the complex nature of the high velocity interaction between bodies or a blast wave spreading and the physical phenomena being analyzed, it is extremely important for the user of the aforementioned tools to have a good understanding of the underlying assumptions and limitations of the models. The advantage of AUTODYN SW is a library of materials suitable for simulation of explosions, blast effects, and impacts with appropriate material constants filled.

A significant limitation for all of these tools is in defining realistic failure criteria for both the structural elements and people. Depending on the scenario, the failure criteria for a person may be set as a blast able to cause a burst ear drum or internal injuries; for another scenario it may be set to a higher blast level to cause significant injury or fatality. One area that has major limitations is the failure of components from combined blast and fragment damage.

Projected or applied protective measures are mostly based on practical experience with blast effects on structures and personnel. In addition to practical experience modern methods such as simulations can be effective. Simulations can be used to predict the effects of an explosion and can help to find out adequate protection measures. Simulations in this field are applicable not only in the military but in the critical infrastructure protection too. Simulations of blast wave interaction with protective concrete walls can help the experts understand the physics and then find the proper solutions for a particular structure.

A VBIED explosion within or immediately nearby a military or critical infrastructure object can cause huge damage to constructions, the collapse of structural members, projections of fragments and casualties that can occur as a result of the effects of a direct blast. Subsequent damage, as well as casualties, can be caused by collapsed constructions or secondary fragments.

There exists many safety measures and protective structures to prevent a VBIED from reaching a target and therefore the main effect of the explosion will mostly affect the protective structures used. One of the most widespread protective constructions is a concrete T-wall but in the case of a VBIED this construction can be not be seen as protection but is responsible for additional damage and casualties due to its downfall or shattering.

References

[1] Vávra, P., Vágenknecht, J. Theory of Blast Effects. 2nd edition. Pardubice: University of Pardubice, FChT, 2008. ISBN 978-80-7395-125-2. [in Czech].

[2] IATG 01.80:2011[E] *Formulae for ammunition management.* UNODA. 2011.

[3] KINGERY, C.N., BULMASH, G., *Airblast Parameters From TNT Spherical Air Burst and Hemispherical Surface Burst.* Technical Report ARBRL-TR-02555, US Army Armament Research and Development Center, April 1984.

[4] MAŇAS, Pavel; KROUPA, Lubomír. Assesment of Blast Attack Effect. In: *Metodológia a metodika analýzy zdrojov ohrozenia vnútornej bezpečnosti SR.* Bratislava: Akadémia Policajného zboru v Bratislave, 2011, p. 145-151. ISBN 978-80-8054-517-8. [in Czech]

[5] Manual on Explosives Safety Risk Analysis – AASTP-4. Edition 1. NATO: NSA, 2008.

[6] Military Explosives. TM 9-1300-214. Washington, DC: Headquarters, Department of the Army, 1984.

[7] MAŇAS, Pavel; KROUPA, Lubomír. Simulation within Force Protection Engineering. In: *ICMT'11 – International Conference on Military Technologies 2011.* Brno: University of Defence, 2011, p. 209-216. ISBN 978-80-7231-787-5.

[8] TNT Equivalents for Various Explosives. National Counterterrorism Center. [Online] URL: <http://www.nctc.gov/site/technical/tnt.html>. [cit. 2004-06-20].

[9] MAŇAS, Pavel; KROUPA, Lubomír. The Blast Effects Simulation Tools within Force Protection Engineering and Critical Infrastructure Security. *Drilling and Blasting Technology*, 2012, vol. 2012, no. September, p. 42-48. ISSN 1788-5671.

[10] DoD Ammunition and Explosives Safety Standards. Department of Defense Explosives Safety Board. [Online] 2008. URL: <http://www.ddesb.pentagon.mil/2008-02-29%20-%20DoD%206055.09-STD,%20DoD%20Ammuntion%20and%20Explosives%20 Safety%20Standards.pdf>. [cit. 2010-05-26].