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THE BLAST EFFECTS SIMULATION TOOLS WITHIN FORCE PROTECTION ENGINEERING AND CRITICAL INFRASTRUCTURE SECURITY

SUMMARY:

In modern asymmetric conflicts, force protection engineering mainly deals with protection against explosion cause by IED's and 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. Blast attacks to public structures present threats that must be taken seriously. Different methods can be used to assess and analyse possible effect of blast attack to construction. One of the options is numerical simulation. Simulations can be used to predict effects of explosion and can help to find out adequate protection measures. The aim of the article is to briefly present use software AUTODYN as a possible way can be use to predict effect of blast attack. Simulations in this fields are applicable nor in the military but in the critical infra-structure protection too.

Keywords: Blast effects, force protection, simulation, critical infrastructure, force protection

INTRODUCTION

Terrorist attacks by explosives means have a long history. But in recent years, the eplosive devices have become the weapon of choice for the majority of terrorist attacks. Such factors as the accessibility of information on the construction of bomb devices, relative ease of manufacturing, mobility and portability, coupled with significant property damage and injuries, are responsible for significant increase in bomb attacks all over the world. In most of cases, structural damage and the glass hazard have been major contributors to death and injury for the targeted buildings.

The most known attacks by explosives are the bombing of the World Trade Centre in New York City in February 1993 and the devastating attack against the Alfred P. Murrah Federal Building in Oklahoma City in April 1995. There are a lot of lesser attacks 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. Any nation can no longer believe themselves immune to terrorist violence within their own borders.

Military forces engaged in the operations are threatened in asymmetric warfare with a large degree of attacks by explosive means labelled as improvised explosives devices (IEDs). 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 lesser level of protection against attack with explosives, are more vulnerable. The use of IEDs is inexpensive but effective and it doesn’t require any sophisticated technology and means. Such factors as the accessibility of information on the construction of bomb devices, relative ease of manufacturing, mobility and portability, coupled with significant property damage and injuries, are responsible for significant increase in bomb attacks all over the world.

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EXPLOSIVE ATTACK THREATS

The effect of the attack particularly depends on the amount and kind of explosives used to 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 utilization of homemade explosives mostly based on perchlorates, hydrogen peroxide mixtures (triacetone triperoxide - TATP) or 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.

Small bomb can be delivered as mail bomb; hand delivered in briefcase or rucksack or can be worn by a person such as suicide bomb or can be placed such as pipe bomb Small bomb can cause the greatest damage and casualties when brought into vulnerable, unsecured areas of the building interior, such as the building lobby, mail room, and retail spaces 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 on the order of two to five kilograms of TNT equivalent. However, larger charge weights, in the 5 to 50 kilograms TNT equivalent range, can be readily carried in rolling cases.

Vehicle bombs (VBIED) bomb size can be calculated on the basis of the loading capacity of a vehicle; are able to deliver a sufficiently large quantity of explosives to cause potentially devastating structural damage. They present one of the biggest threats to public, especially for municipal buildings, public places, monuments and symbols, military installations and critical infrastructure and they can result in a greater effect on the target. The explosion within or immediately nearby a military installation can cause a huge damage on constructions, the collapse of protective walls, projections of fragments and casualties that can occur in result of the direct blast effects. Subsequent damage as well as casualties can be caused by collapsed constructions or secondary fragments.

Fig. 1: Effect of VBIED on public buildings in Oslo, July 22, 2011

Fig. 2: Effect of VBIED on the target protective walls

In general, the effect of the blast particularly 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 centre of gravity of the charge to the component of interest. The bomb size depends on delivering capacity of attackers and is measured in equivalent charge of TNT.

Bomb size can be calculated on the basis of the loading capacity of a person or a vehicle. For practical reasons the representative bombs are used and their explosive capacity are given in table 1.

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

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

Most structural damage from an external explosion is caused by response to airblast, fragment impact, and ground shock. The extent and severity of damage and injuries in result of an explosive attack can be assumed on the base of the size of the explosion, distance from the explosion site, and assumptions about the construction. Damage due to the airblast may be divided into direct airblast effects and progressive collapse.

Direct airblast effects are damage caused by the high-intensity pressures of the air blast close to the explosion. These may induce localized failure of exterior walls, windows, roof systems, floor systems, and columns. Progressive collapse refers to 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 produce 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 pressures that an explosion exerts 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.

ASSESMENT OF BLAST EFFECTS

Different methods can be used to analyse and assess possible subsequent effects of blast attack on protected or presumed object or on human. Regarding VBIED, as a result of applied protective structures and safety measures VBIED 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 following table we can estimate the range of damage or injury.

Table 2 Damage criteria for structures or components due to overpressure – examples [kPa]

Damage	**Occasional**	**Minor damage**	**Medium damage**	**Heavy damage**	**Destruction**
Object	**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	-	-

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

- Empirical calculation based on scaled distance from TNT charge and empirical formulae of overpressure, pressure impulse and time of arrival and time of duration;
- Semi-empirical calculation based on the same formulae like previous 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 calculation of blast effect are mainly focused on spreading of pressure wave in the air and calculation of overpressure (see Fig. 3) for both types of burst – air burst and surface burst (see Fig. 4). Numerical methods based mainly on Euler or Lagrange solver allow us to compute 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.

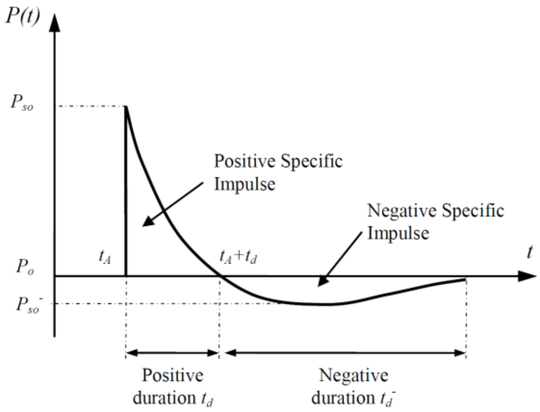

Fig. 3a: Dependency of overpressure at given distance on time of duration after explosion

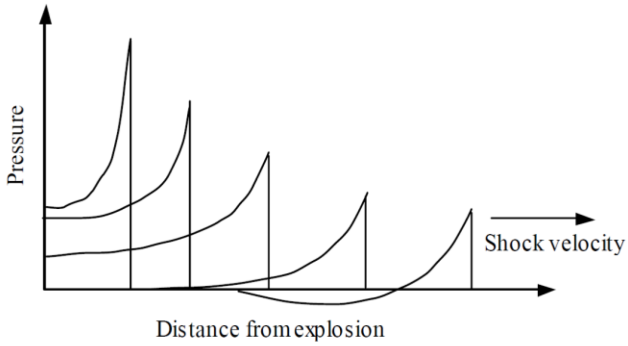

Fig. 3b: Chart of maximum pressure at distance from explosion

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

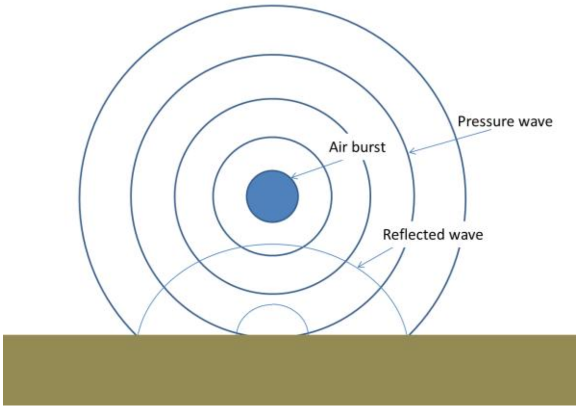

Fig. 4a: Spherical free air burst

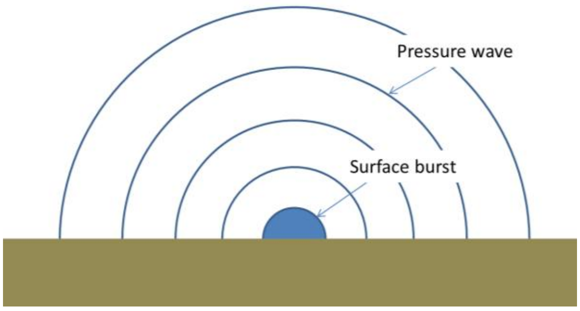

Fig. 4b: Hemispherical surface burst

Following paragraphs shows 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 possibility to simplify solution.

2D AND 3D SIMULATION OF BLAST WAVE

Euler solver is very effective for simulation of blast pressure wave spreading in the air or simulation of blast effect on structure when charge detonates in some distance from object of interest. Euler solver is using 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 transport terms of the mass, energy, and momentum each computational step.

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

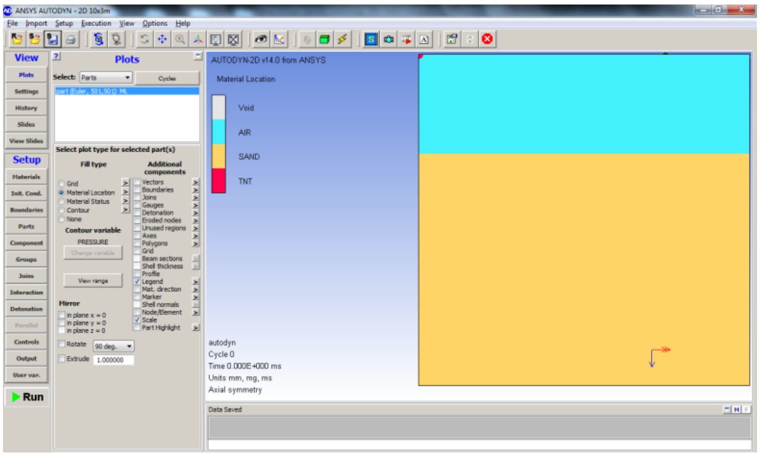

Fig. 5a: 2D axis symmetry simulation of spherical free air burst – initial conditions in AUTODYN

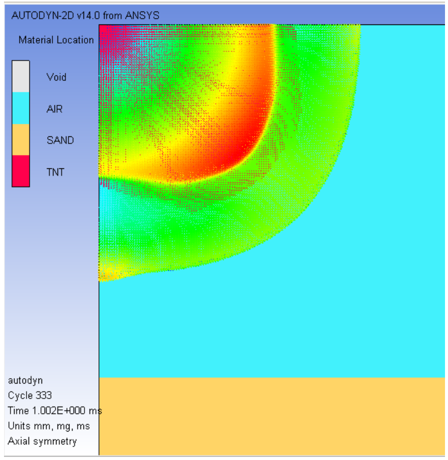

Fig. 5b: Detail of "flowing" materials through 2D i-j mesh, 1 ms after detonation of TNT charge

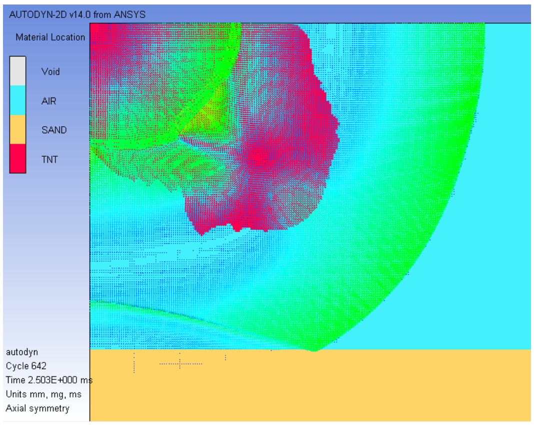

Fig. 5c: Beginning of reflection of pressure wave, 2.5 ms after detonation of TNT charge

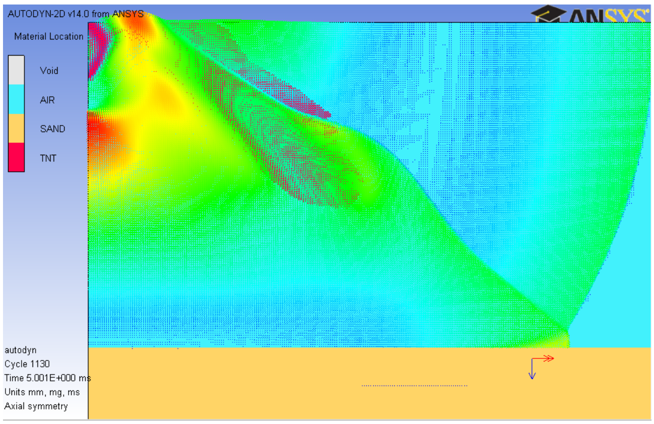

Fig. 5d: Initialization of "triple point" of reflected wave, 5 ms after detonation of TNT charge

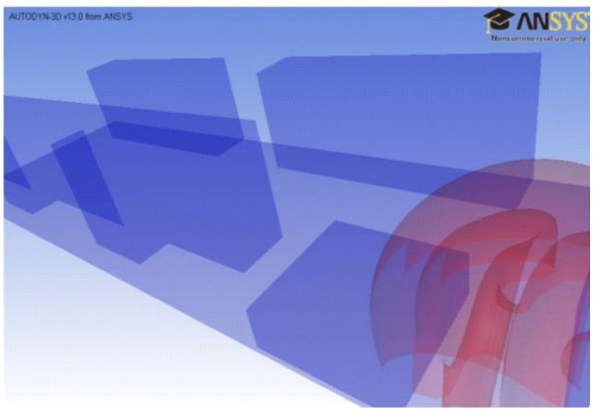

Fig. 6a: Simulation of blast insight of urban area, 20 ms after detonation of TNT charge

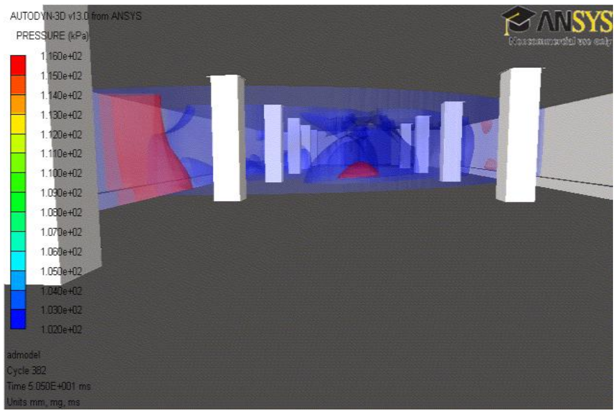

Fig. 6b: Simulation of blast insight of buildings, 50 ms after detonation of TNT charge

These simulations conducted at our department allow us to assess consequences of blast with criteria according to Table 2. 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.

BLAST BEHIND AND IMPACT ONTO CONCRETE PROTECTIVE WALL

Lagrange solver is effective for simulation of interaction of bodies, when one body penetrate the other (see Fig. 7 and 8). This solver is using the computational mesh that is connected with the continuum, the same way like classic FEM. Thus, it deforms in time following the continuum deformation. No transport terms are needed, 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 new more regular mesh at certain times and therefore it introduces into the solution similar errors like transport terms above.

Fig. 7a: Damaged protective wall after VBIED atack

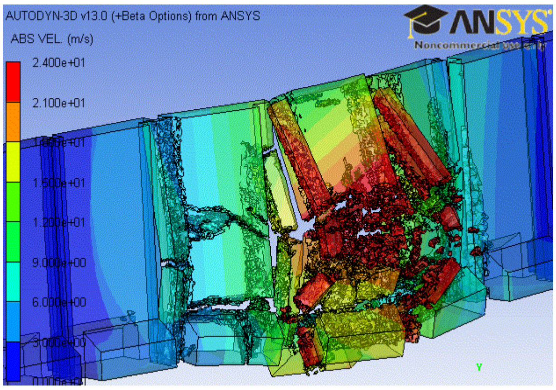

Fig. 7b: Simulation of blast behind T-Walls, 25 ms after detonation of TNT charge

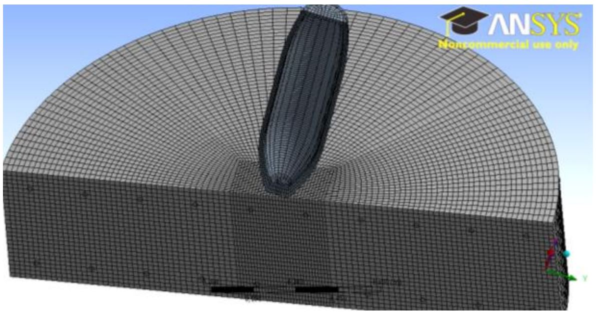

Fig. 8a: Simulation of penetration of projectile into RC slab – Lagrangian mesh

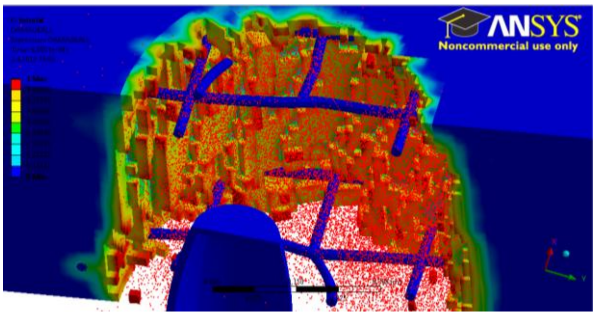

Fig. 8b: Simulation of penetration of projectile into RC slab – damages after 10ms

These kinds of simulations allow us to assess e.g. interaction between bodies after explosion or damage level insight of bodies subjected to blast wave. The most important parameters are impact velocity, damage level and strain of materials; this result can be animated and then give us good view into mechanism of this incident.

CONCLUSION

Based on knowledge of blasting action and convenient software the effect of blast attack can be simulated to predict outgrowth of blast to construction. Software AUTODYN can be successfully used for the simulation. The significant advantage of AUTODYN SW is a library of materials suitable for simulation of explosions, blast effects, and impacts with appropriate material constants filled.

Modern software tools like AUTODYN can help experts to properly assess threats in asymmetric conflicts for reasonable cost. Due to the complex nature of the high velocity interaction between bodies or blast wave spreading and physical phenomena being analysed, it is extremely important for the user of mentioned tools to have a good understanding of the underlying assumptions and limitations of the models.

A significant limitation for all of these tools is in defining realistic failure criteria for both the structural elements and the humans. Depending on the scenario, the failure criteria for a human may be set as the blast to cause a burst ear drum, 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. This is the area for future research at our department.

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TÁMOP-4.2.1.B-11/2/KMR-2011-0001 Kritikus infrastruktúra védelmi kutatások „A projekt az Európai Unió támogatásával, az Európai Szociális Alap társfinanszírozásával valósul meg."

„The project was realised through the assistance of the European Union, with the co-financing of the European Social Fund."