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# Architectural And Structural Design Blast Resistant Buildings

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**Abstract:** The increase in the number of terrorist attacks especially in the last few years has shown that the effect of blast loads on buildings is a serious matter that should be taken into consideration in the design process. Although these kinds of attacks are exceptional cases, man-made disasters; blast loads are in fact dynamic loads that need to be carefully calculated just like earthquake and wind loads. The objective of this study is to shed light on blast resistant building design theories, the enhancement of building security against the effects of explosives in both architectural and structural design process and the design techniques that should be carried out. Firstly, explosives and explosion types have been explained briefly. In addition, the general aspects of explosion process have been presented to clarify the effects of explosives on buildings. To have a better understanding of explosives and characteristics of explosions will enable us to make blast resistant building design much more efficiently. Essential techniques for increasing the capacity of a building to provide protection against explosive effects is discussed both with an architectural and structural approach.

**Keywords:** Terrorist attacks, Blast loads, Exceptional, Explosion.

## I. INTRODUCTION

The increase in the number of terrorist attacks especially in the last few years has shown that the effect of blast loads on buildings is a serious matter that should be taken into consideration in the design process. Although these kinds of attacks are exceptional cases, man-made disasters; blast loads are in fact dynamic loads that need to be carefully calculated just like earthquake and wind loads. The objective of this study is to shed light on blast resistant building design theories, the enhancement of building security against the effects of explosives in both architectural and structural design process and the design techniques that should be carried out. Firstly, explosives and explosion types have been explained briefly. In addition, the general aspects of explosion process have been presented to clarify the effects of explosives on buildings. To have a better understanding of explosives and characteristics of explosions will enable us to make blast resistant building design much more efficiently. Essential techniques for increasing the capacity of a building to provide protection against explosive effects is discussed both with an architectural and structural approach. Damage to the assets, loss of life and social panic are factors that have to be minimized if the threat of terrorist action cannot be stopped. Designing the structures to be fully blast resistant is not an realistic and economical option, however current engineering and architectural knowledge can enhance the new and existing buildings to mitigate the effects of an explosion.

## II. LITERATURE SURVEY

The need and requirements for blast resistance in buildings have evolved over recent years. Buildings have become more complex and have increased in size thus increasing the risk of accidental explosions. Such explosions have demolished the buildings, in some cases resulting in substantial personnel causalities and business losses. Such events have heightened the concerns of the industry, plant management, and regulatory agencies about the issues of blast protection in buildings have the potential for explosions. Generally, these issues relate to plant building safety and risk management to prevent or minimize the occurrence of such incidents and to siting, design, and operations.

### A. Explosion - Major of All Terrorist Activities

The probability that any single building will sustain damage from accidental or deliberate explosion is very low, but the cost for those who are unprepared is very high.

### B. Expected Terrorist Blast On Structures

- External car bomb
- Internal car bomb
- Internal package
- Suicidal car bombs

### C. Major Cause of Life Loss After The Blast

- Flying debris
- Broken glass
- Smoke and fire
- Blocked glass
- Power loss
- Communications breakdown
- Progressive collapse of structure

### D. Goals of Blast Resistant Design

The goals of blast-resistant design are to :

- Reduce the severity of injury

- Facilitate rescue
- Expedite repair
- Accelerate the speed of return to full operation.

**E. Basic Requirements to Resist Blast Loads**

To resist blast loads, The first requirement is to determine the threat. The major threat is caused by terrorist bombings. The threat for a conventional bomb is defined by two equally important elements, the bomb size, or charge weight, and the standoff distance - the minimum guaranteed distance between the blast source and the target.Another requirement is to keep the bomb as far away as possible, by maximizing the keepout distance. No matter what size the bomb, the damage will be less severe the further the target is from the source. Structural hardening should actually be the last resort in protecting a structure; detection and prevention must remain the first line of defense. As terrorist attacks range from the small letter. .bomb to the gigantic truck bomb as experienced in Okla-homa City,the mechanics of a conventional explosion and their effects on a target must be addressed.

**F. Mechanics of a Conventional Explosion**

With the detonation of a mass of TNT at or near the ground surface, the peak blast pressures resulting from this hemispherical explosion decay as a function of the distance from the source as the ever-expanding shock front dissipates with range. The incident peak pressures are amplified by a reflection factor as the shock wave encounters an object or structure in its path. Except for specific focusing of high intensity shock waves at near 45 incidence, these reflection factors are typically greatest for normal incidence (a surface adjacent and perpendicular to the source) and diminish with the angle of obliquity or angular position relative to the source. Reflection factors depend on the intensity of the shock wave, and for large explosives at normal incidence these reflection factors may enhance the incident pressures by as much as an order of magnitude. Charges situated extremely close to a target structure impose a highly impulsive, high intensity pressure load over a localized region of the structure; charges situated further away produce a lower-intensity, longer-duration uniform pressure distribution over the entire structure. In short by purely geometrical relations, the larger the stand- off, the more uniform the pressure distribution over the target. Eventually, the entire structure is engulfed in the shock wave, with reflection and diffraction effects creating focusing and shadow zones in a complex pattern around the structure. Following the initial blast wave, the structure is subjected to a negative pressure, suction phase and eventually to the quasi-static blast wind. During this phase, the weakened structure may be subjected to impact by debris that may cause additional damage.

## III. ARCHITECTURAL ASPECT OF BLAST RESISTANT BUILDING DESIGN

**A. General**

The target of blast resistant building design philosophy is minimizing the consequences to the structure and its inhabitants in the event of an explosion. A primary requirement is the prevention of catastrophic failure of the entire structure or large portions of it. It is also necessary to minimize the effects of blast waves transmitted into the building through openings and to minimize the effects of projectiles on the inhabitants of a building. However, in some cases blast resistant building design methods, conflicts with aesthetical concerns, accessibility variations, fire fighting regulationsand the construction budget restrictions.

**B. Planning And Layout**

Much can be done at the planning stage of a new building to reduce potential threats and the associated risks of injury and damage. The risk of a terrorist attack, necessity of blast protection for structural and non-structural members, adequate placing of shelter areas within a building should be considered for instance. In relation to an external threat, the priority should be to create as much stand-off distance between an external bomb and the building as possible. On congested city centers there may be little or no scope for repositioning the building, but what small stand-off there is should be secured where possible. This can be achieved by strategic location of obstructions such as bollards, trees and street furniture. Fig1 shows a possible external layout for blast safe planning.

**C. Structural Form and Internal Layout**

Structural form is a parameter that greatly affects the blast loads on the building. Arches and domes are the types of structural forms that reduce the blast effects on the building compared with a cubicle form. The plan-shape of a building also has a significant influence on the magnitude of the blast load it is likely to experience. Complex shapes that cause multiple reflections of the blast wave should be discouraged. Projecting roofs or floors, and buildings that are U-shaped on plan are undesirable for this reason. It should be noted that single story buildings are more blast resistant compared with multi-story buildings if applicable.

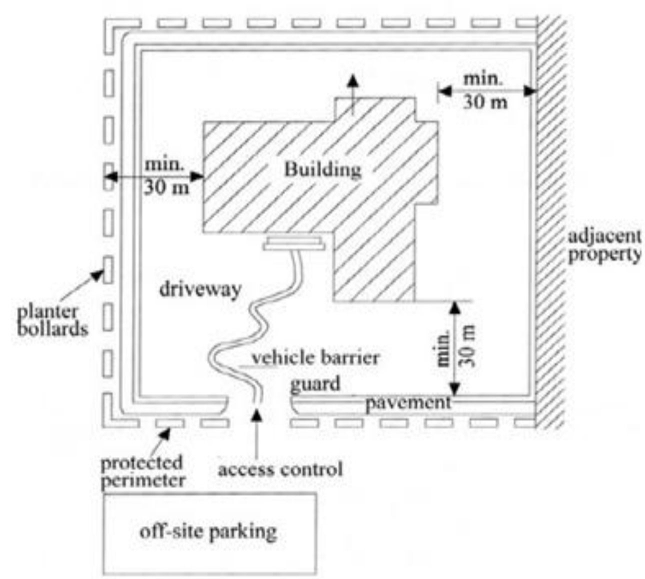


**Fig1. Schematic layout of site for protection against bombs.**

## IV. STRUCTURAL ASPECT OF BLAST RESISTANT BUILDING

The front face of a building experiences peak overpressures due to reflection of an external blast wave. Once the initial blast wave has passed the reflected surface of the building, the peak overpressure decays to zero. As the sides and the top faces of the building are exposed to overpressures (which has no reflections and are lower than the reflected overpressures on the front face), a relieving effect of blast overpressure is experienced on the front face. The rear of the structure experiences no pressure until the blast wave has traveled the length of the structure and a compression wave has begun to move towards the centre of the rear face. Therefore the pressure built up is not instantaneous. On the other hand, there will be a time lag in the development of pressures and loads on the front and back faces.This time lag causes translational forces to act on the building in the direction of the blast wave.

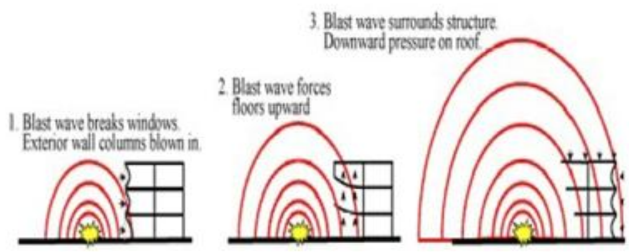


**Fig2. Sequence of air-blast effects.**

Blast loadings are extra ordinary load cases however, during structural design, this effect should be taken into account with other loads by an adequate ratio. Similar to the static loaded case design, blast resistant dynamic design also uses the limit state design techniques which are collapse limit design and functionality limit design. In collapse limit design the target is to provide enough ductility to the building so that the explosion energy is distributed to the structure without overall collapse. For collapse limit design the behavior of structural member connections is crucial. In the case of an explosion, significant translational movement and moment occur and the loads involved should be transferred from the beams to columns. The structure doesn't collapse after the explosion however it cannot function anymore. Functionality limit design however, requires the building to continue functionality after a possible explosion occurred. Only non-structural members like windows or cladding may need maintenance after an explosion so that they should be designed ductile enough. When the positive phase of the shock wave is shorter than the natural vibration period of the structure, the explosion effect vanishes before the structure responds. This kind of blast loading is defined as impulsive loading. If the positive phase is longer than the natural vibration period of the structure, the load can be assumed constant when the structure has maximum deformation. This maximum deformation is a function of the blast loading and the structural rigidity. This kind of blast loading is defined as quasi-static loading. Finally, if the positive phase duration is similar to the natural vibration period of the structure, the behavior of the structure becomes quite complicated. This case can be defined as dynamic loading. Frame buildings designed to resist gravity, wind loads and earthquake loads in the normal way have frequently been found to be deficient in two respects.

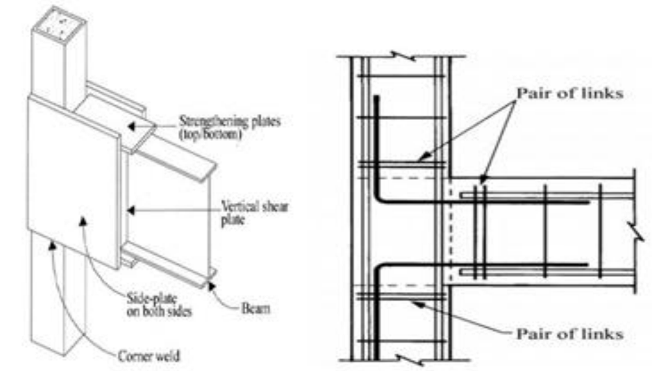


**Fig3. Enhanced beam-to-column connection details for steelwork and reinforced concrete.**

When subjected to blast loading; the failure of beam-to-column connections and the inability of the structure to tolerate load reversal .Beam-to-column connections can be subjected to very high forces as the result of an explosion. These forces will have a horizontal component arising from the walls of the building and a vertical component from the differential loading on the upper and lower surfaces of floors. Providing additional robustness to these connections can be a significant enhancement. In the connections, normal details for static loading have been found to be inadequate for blast loading. Especially for the steelwork beam-to-column connections, it is essential for the connection to bear inelastic deformations so that the moment frames could still operate after an instantaneous explosion. These enhancements are intended to reduce the risk of collapse or the connection be damaged, possibly as a result of a load reversal on the beam It is vital that in critical areas, full moment-resisting connections are made in order to ensure the load carrying capacity of structural members after an explosion. Beams acting primarily in bending may also carry significant axial load caused by the blast loading. On the contrary, columns are predominantly loaded with axial forces under normal loading conditions, however under blast loading they may be subjected to bending. Such forces can lead to loss of load-carrying capacity of a section. In the case of an explosion, columns of a reinforced concrete structure are the most important members that should be protected. Two types of wrapping can be applied to provide this. Wrapping with steel belts or wrapping with carbon fiber reinforced polymers(CFRP).Cast-insitu reinforced concrete floor slabs are the preferred option for blast resistant buildings, but it may be necessary to consider the use of precast floors in some circumstances. Precast floor units are not recommended for use at first floor where the risk from an internal explosion is greatest. Lightweight roofs and more particularly, glass roofs should be avoided and a reinforced concrete or precast concrete slab is to be preferred.

### A. Structural Failure

An explosion will create blast wave. The air-blast shock wave is the primary dam- age mechanism in an explosion. The pressures it exerts on building surfaces may be several orders of magnitude greater than the loads for which the building is designed. The shock wave will penetrate and surround a structure and acts in directions that the building may not have been designed for, such as upward force on the floor system. In terms of sequence of response, the air-blast first impinges on the weakest point in the vicinity of the device closest to the explosion, typically the exterior envelope of the building. The explosion pushes on the exterior walls at the lower stories and may cause wall failure and window breakage. As the shock wave continues to expand, it enters the structure, pushing both upward and downward on the floor slabs.

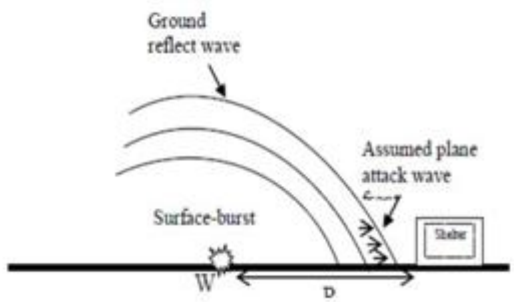


**Fig4. Shock Front from Air Burst.**

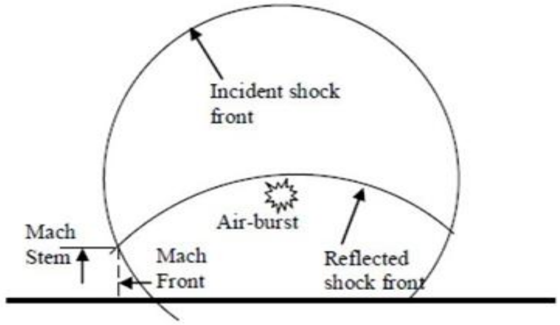


**Fig5. Shock Front from Surface Burst.**

### B. Comparison of Blast And Seismic Loading

Blast wave and seismic loading are two different type of extreme force that may cause structural failure. However, they share some common similarities. Similarities between seismic and blast loading includes the following:

- Dynamic loads and dynamic structural response.
- Involve inelastic structural response.
- Design considerations will focus on life safety as opposed to preventing structural damage.
- Other considerations: Nonstructural damage and hazards.
- Performance based design: life safety issues and progressive collapse.
- Structural integrity: includes ductility, continuity, and redundancy; balanced design.

The differences between these two types of loading include:

- Blast loading is due to a propagating pressure wave as opposed to ground shaking.
- Blast results in direct pressure loading to structure; pressure is in all directions whereas a Seismic event is dominated by lateral load effects.
- Blast loading is of higher amplitude and very short duration compared with a seismic event.
- Magnitude of blast loading is difficult to predict and not based on geographical location.
- Blast effects are confined to structures in the immediate vicinity of event because pressure decays rapidly with distance; local versus regional even.
- Progressive collapse is the most serious consequence of blast loading.

## V. DAMAGE EVALUATION PROCEDURE FOR BUILDING SUBJECTED TO BLAST IMPACT

Slab failure is typical in blasts due to large surface area subjected to upward pressure not considered in gravity design. Small database on blast effects on structures. Seismic-resistant design is mature compared with blast-resistant design. In summary, while the effect of blast loading is localized compared with an earth- quake, the ability to sustain local damage without total collapse (structural integrity) is a key similarity between seismic-resistant and blast-resistant design. In this study, the evaluation data that had been listed in inspection form is adapted and modified from inspection form for building after an earthquake. Even though, seismic loading will cause global response to building compared to blast loading which will cause localized response,but similar damage assessment procedure could be used.

## VI. CASE STUDY

### A. World Trade Center Collapse

The collapse of the World Trade Center (WTC) towers on September 11, 2001, was as sudden as it was dramatic; the complete destruction of such massive buildings shocked nearly everyone. Immediately afterward and even today, there is widespread specula- tion that the buildings were structurally deficient, that the steel columns melted, or that the fire suppression equipment failed to operate. In order to separate the fact from the fiction, I have attempted to quantify various details of the collapse.

### B. The Design

The towers were designed and built in the mid-1960s through the early 1970s each tower was 64 m square, standing 411 m above street level and 21 m below grade. This produces a height-to-width ratio of 6.8. The total weight of the structure was roughly 500,000 t. The building is a huge sail that must resist a 225 km/h hurricane. It was designed to resist a wind load of 2 kPaa total of lateral load of 5,000 t. In order to make each tower capable of withstanding this wind load, the architects selected a lightweight perimeter tube design consisting of 244 exterior columns of 36 cm square steel box section on 100 cm centers(figure 3). This permitted windows more than one-half meter wide. Inside this outer tube there was a 27 m 40 m core, which was designed to support the weight of the tower. It also housed the elevators, the stairwells, and the mechanical risers and utilities. Web joists 80 cm tall connected the core to the perimeter at each story. Concrete slabs were poured over these joists to form the floors. In essence, the building is an egg- crate construction, i.e. 95 percent air. The egg-crate construction made a redundant structure (i.e., if one or two columns were lost, loads would shift into adjacent columns and the building would remain standing). The WTC was primarily a lightweight steel structure; however, its 244 perimeter columns made it one of the most redundant and one of the most resilient skyscrapers.

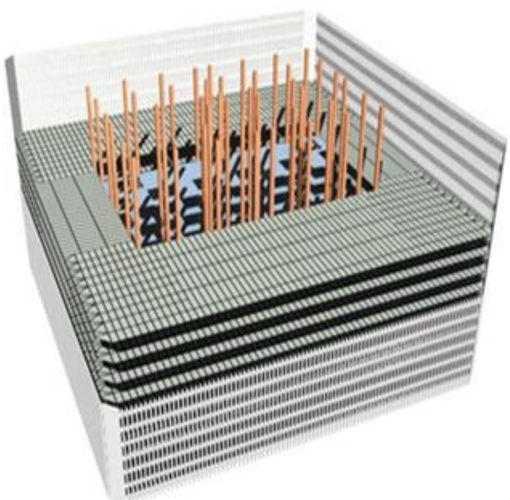

**Fig6. A cutaway view of WTC structure.**

**C. The Airplane Impact**

The early news reports noted how well the towers withstood the initial impact of the aircraft; however, when one recognizes that the buildings had more than 1,000 times the mass of the aircraft and had been designed to resist steady wind loads of 30 times the weight of the aircraft, this ability to withstand the initial impact is hardly surprising. Furthermore, since there was no significant wind on September 11, the outer perimeter columns were only stressed before the impact to around 1/3 of their 200 MPa design allowable. The only individual metal component of the aircraft that is comparable in strength to the box perimeter columns of the WTC is the keel beam at the bottom of the aircraft fuselage. While the aircraft impact undoubtedly destroyed several columns in the WTC perimeter wall, the number of columns lost on the initial impact was not large and the loads were shifted to remaining columns in this highly redundant structure. Of equal or even greater significance during this initial impact was the explosion when 90,000 Lgallons of jet fuel, comprising nearly 1/3 of the aircrafts weight, ignited. The fire is the most misunderstood part of the WTC collapse. Even today, the media report (and many scientists believe) that the steel melted. It is argued that the jet fuel burns very hot, especially with so much fuel present. This is not true. Part of the problem is that people often confuse temperature and heat. While they are related, they are not the same. Thermodynamically, the heat contained in a material is related to the temperature through the heat capacity and the mass.

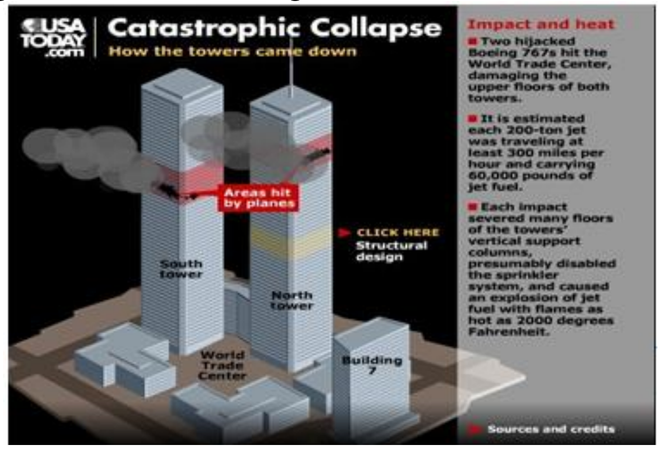


**Fig7. A graphic illustration, from the USA Today newspaper web site, of the World Trade Center points of impact.**

**Fig8. Flames and debris exploded from the World Trade Center south tower immediately after the airplanes impact. The black smoke indicates a fuel-rich fire busted jet. This is what occurs in a jet engine, and this is the flame type that generates the most intense heat.**

Temperature is defined as an intensive property, meaning that it does not vary with the quantity of material, while the heat is an extensive property, which does vary with the amount of material. One way to distinguish the two is to note that if a second log is added to the fireplace, the temperature does not double; it stays roughly the same, but the length of time the fire burns, doubles and the heat so produced is doubled. Thus, the fact that there were 90,000 L of jet fuel on a few floors of the WTC does not mean that this was an unusually hot fire. The temperature of the fire at the WTC was not unusual, and it was most definitely not capable of melting steel. In combustion science, there are three basic types of flames, namely, a jet burner, a pre-mixed flame, and a diffuse flame. A jet burner generally involves mixing the fuel and the oxidant in nearly stoichiometric proportions and igniting the mixture in a constant-volume chamber. In a pre-mixed flame, the same nearly stoichiometric mixture is ignited as it exits a nozzle,under constant pressure conditions. It does not attain the flame velocities of a jet burner. An oxyacetylene torch or a Bunsen burner is a premixed flame. In a diffuse flame, the fuel and the oxidant are not mixed before ignition, but flow together in an uncontrolled manner and combust when the fuel/oxidant ratios reach values within the flammable range. A fireplace flame is a diffuse flame burning in air, as was the WTC fire. Diffuse flames generate the lowest heat intensities of the three flame types.

## VII. CONCLUSION

The aim in blast resistant building design is to prevent the overall collapse of the building and fatal damages. Despite the fact that, the magnitude of the explosion and the loads caused by it cannot be anticipated perfectly, the most possible scenarios will let to find the necessary engineering and architectural solutions for it. In the design process it is vital to determine the potential danger and the extent of this danger. Most importantly human safety should be provided. Moreover, to achieve functional continuity after an explosion, architectural and structural factors should be taken into account in the design process, and an optimum building plan should be put together. This study is motivated from making buildings in a blast resistant way, pioneering to put the necessary regulations into practice for preventing human and structural loss due to the blast and other human-sourced hazards and creating a common sense about the explosions that they are possible threats in daily life. In this context, architectural and structural design of buildings should be specially considered. During the architectural design, the behavior under extreme compression loading of the structural form, structural elements e.g. walls, flooring and secondary structural elements like cladding and glazing should be considered carefully. In conventional de- sign, all structural elements are designed to resist the structural loads. But it should be remembered that, blast loads are unpredictable, instantaneous and extreme. Therefore, it is obvious that a building will receive less damage with a selected safety level and a blast resistant architectural design. On the other hand, these kinds of buildings will less attract the terrorist attacks.Structural design after an environmental and architectural blast resistant design, as well stands for a great importance to prevent the overall collapse of a building. With correct selection of the structural system, well designed beam-column connections, structural elements designed adequately, moment frames that transfer sufficient load and high quality material; its possible to build a blast resistant building. Every single member should be designed to bear the possible blast loading. For the existing structures, retrofitting of the structural elements might be essential. Although these precautions will increase the cost of construction, to protect special buildings with terrorist attack risk like embassies, federal buildings or trade centers is unquestionable.

## VIII. REFERENCES

[1]Koccaz Z. (2004) Blast Resistant Building Design, MSc Thesis, Istanbul Techni- cal University, Istanbul, Turkey.

[2]Smith P.D., Hetherington J.G. (1994) Blast and ballistic loading of structures. Butterworth Heinemann.

[3]Yandzio E., Gough M. (1999). Protection of Buildings Against Explosions, SCI Publication, Berkshire, U.K.

[4]Website:www.iitk.ac.in/nicee/wcee/article/14-05-01-0536.PDF

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