Enhancement of Strcture Design for Blast Resistant

Ambesh Ratnu [1*], Prof. A.K. Gupta [2],

[1*] Ph.D Student, Department of Structure Engineering, MBM-Jodhpur, Rajasthan, India ,
[2] Professor, Department of Structure Engineering, MBM-Jodhpur, Rajasthan, India.

***Abstract*— A bomb explosion within or immediately nearby a building can cause catastrophic damage on the building's external and internal structural frames, collapsing of walls, blowing out of large expanses of windows, and shutting down of critical life-safety systems. Loss of life and injuries to occupants can result from many causes, including direct blast-effects, structural collapse, debris impact, fire, and smoke. The indirect effects can combine to inhibit or prevent timely evacuation, thereby contributing to additional casualties. In addition, major catastrophes resulting from gas-chemical explosions result in large dynamic loads, greater than the original design loads, of many structures. Due to the threat from such extreme loading conditions, efforts have been made during the past three decades to develop methods of structural analysis and design to resist blast loads. Studies were conducted on the behavior of structural concrete subjected to blast loads. These studies gradually enhanced the understanding of the role that structural details play in affecting the behavior.**

***Keywords*— *Blast Explosion, Resistant Structure, SDOF*.**

I. Introduction

In the past few decades considerable emphasis has been given to problems of blast and earthquake. The earthquake problem is rather old, but most of the knowledge on this subject has been accumulated during the past fifty years. The blast problem is rather new; information about the development in this field is made available mostly through publication of the Army Corps of Engineers, Department of Defense, U.S. Air Force and other governmental office and public institutes. Much of the work is done by the Massachusetts Institute of Technology, The University of Illinois, and other leading educational institutions and engineering firms. The September 11 attacks were a series of four coordinated terrorist attacks by the Islamic terrorist group al-Qaeda against the United States on the morning of Tuesday, September 11, 2001. The attacks killed 2,996 people, injured over 6,000 others, and caused at least $10 billion in infrastructure and property damage. Additional people died of 9/11-related cancer and respiratory diseases in the months and years following the attacks.

The 2008 Mumbai attacks (also referred to as 26/11) were a group of terrorist attacks that took place in November 2008, when 10 members of Lashkar-e-Taiba, an Islamic terrorist organization based in Pakistan, carried out a series of 12 coordinated shooting and bombing attacks lasting four days across Mumbai. The attacks, which drew widespread global condemnation, began on Wednesday 26 November and lasted until Saturday 29 November 2008. At least 174 people died, including 9 attackers, and more than 300 were wounded. Eight of the attacks occurred in South Mumbai at Chhatrapati Shivaji Terminus, The Oberoi Trident, The Taj Palace & Tower, Leopold Cafe, Hospital, The Nariman House Jewish community center, the Cinema, and in a lane behind the Times of India building and St. Xavier's College. There was also an explosion at Mazagaon, in Mumbai's port area, and in a taxi at Vile Parle.

In recent years, the explosive loads have gained considerable attention due to different events, accidental or intentional, over important structures all over the world. As a consequence, in the last decade there was an important activity in the research of explosive loads. Initially, this work was mostly empirical, but in recent years, important new methods have been developed. The dynamic loads originating from explosions result in strain rates in the material of about 10^{-1} to 10^{3} s^{-1}. These extreme loads produce a special behavior in the material that is characterized, among other effects, by an increase in strength compared with normal, static properties.

These attacks on buildings may not be eliminated completely, but the effects of these attacks on buildings and structures can be mitigated to a large extent with precautions and pre-emptive strategies related to security and by structural hardening. Security measures are highly effective and economical in reducing the risk to a structure and its occupants however structural hardening is required to minimize the consequences of any security lapse. The cost of upgrading the building for a "certain level" of resistance against terrorist threats may not be significant as compared to the overall lifetime costs of the building (including the land value, and security monitoring). Predicting the exact response is difficult due to the large number of parameters involved and the rapid time varying nature of phenomenon therefore understanding the building and its functional use, and possible threats due to terrorist attacks, is essential in identifying strategies that are likely to be most effective to prevent detrimental of the attacks.

II. REVIEW ON BLAST RESISTANT STRUCTURE

Explosive detonations create an incident blast wave, characterized by an almost instantaneous rise from atmospheric pressure to a peak overpressure. As the shock front expands pressure decays back to ambient pressure, a negative pressure phase occurs that is usually longer in duration than the positive phase as shown in Figure 1.1. The negative phase is usually less important in a design than the positive phase. When the incident pressure wave impinges on a structure that is not parallel to the direction of the wave's travel, it reflected and reinforced, producing what is known as reflected pressure. The reflected pressure is always greater than the incident pressure at the same distance from the explosion. The reflected pressure varies with the angle of incidence of the shock wave. When the shock wave impinges on a surface that is perpendicular to the direction it is traveling, the point of impact will experience the maximum reflected pressure. When the reflecting surface is parallel to the blast wave, the minimum reflected pressure or incident pressure will be experienced. In addition to the angle of incidence, which is function of the net explosive weight and distance from the detonation.

The reflected pressure coefficient equals the ratio of the peak reflected to the peak incident pressure.

When a shockwave strikes a surface it is reflected back. Due to the reflection and corresponding momentum change there is a rise in pressure called reflected overpressure on the surface. The magnitude of reflected overpressure is dependent on the angle of incidence.

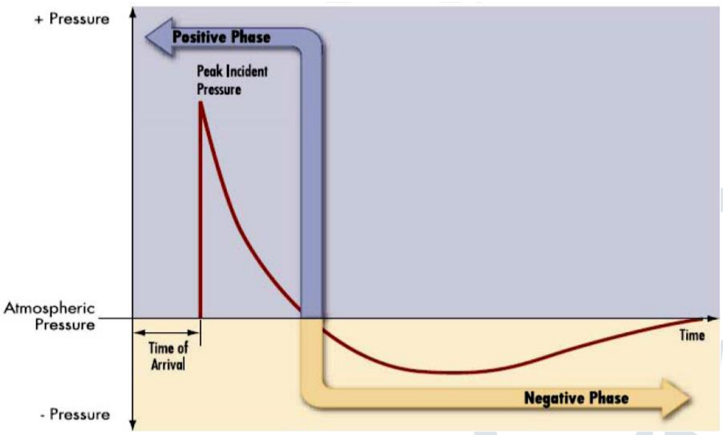

Fig 1: Overpressure-time history indicating sharp initial drop and extended negative phase (FEMA 426, 2003) [9]

The shockwave is followed by blast wind which contains the explosion products, ambient air and debris sucked in by the shockwave. The pressure caused by this wind is called dynamic pressure. The decay of dynamic pressure is similar to the side-on overpressure.

Impulse is a measure of the energy from an explosion imparted to a building and can be obtained by computing the area of the pressure-time curve of the shockwave. The impulse of an explosion is directly proportional to energy of the explosion.

A. Khadid et al. (2007) [1] studied the fully fixed stiffened plates under the effect of blast loads to determine the dynamic response of the plates with different stiffener configurations and considered the effect of mesh density, time duration and strain rate sensitivity. He used the finite element method and the central difference method for the time integration of the nonlinear equations of motion to obtain numerical solutions.

A.K. Pandey et al. (2006) [2] studied the effects of an external explosion on the outer reinforced concrete shell of a typical nuclear containment structure. The analysis has been made using appropriate non-linear material models till the ultimate stages. An analytical procedure for nonlinear analysis by adopting the above model has been implemented into a finite element code DYNAIB.

Alexander M. Remennikov (2003) [3] studied the methods for predicting bomb blast effects on buildings. When a single building is subjected to blast loading produced by the detonation of high explosive device. Simplified analytical techniques used for obtaining conservative estimates of the blast effects on buildings. Numerical techniques including Lagrangian, Eulerian, Euler- FCT, ALE, and finite element modelling used for accurate prediction of blast loads on commercial and public buildings.

J. M. Dewey (1971) [17] studied the properties of the blast waves obtained from the particle trajectories. First time he introduced the effect of spherical and hemispherical TNT (trinitrotoluene) in blast waves and determined the density throughout the flow by application of the Lagrangian conservation of mass equation which used for calculating the pressure by assuming the adiabatic flow for each air element between the shock fronts. The temperature and the sound speed found from the pressure and density, assuming the perfect gas equation of states.

Kirk A. Marchand et al. (2005) [19] reviews the contents of American Institute of Steel Construction, Inc. for facts for steel buildings give a general science of blast effects with the help of numbers of case studies of the building which are damaged due to the blast loading i.e. Murrah Building, Oklahoma City, Khobar Towers , Dhahran, Saudi Arabia and others. Also studied the dynamic response of a steel structure to the blast loading and shows the behavior of ductile steel column and steel connections for the blast loads.

M. V. Dharaneepathy et al. (1995) [20] studied the effects of the stand-off distance on tall shells of different heights, carried out with a view to study the effect of distance (ground-zero distance) of charge on the blast response. An important task in blast-resistant design is to make a realistic prediction of the blast pressures. The distance of explosion from the structure is an important datum, governing the magnitude and duration of the blast loads. The distance, known as 'critical ground-zero distance', at which the blast response is a maximum. This critical distance should be used as design distance, instead of any other arbitrary distance.

Ronald L. Shopev (2006) [24] studied the response of wide flange steel columns subjected to constant axial load and lateral blast load. The finite element program ABAQUS was used to model with different slenderness ratio and boundary conditions. Non-uniform blast loads were considered. Changes in displacement time histories and plastic hinge formations resulting from varying the axial load were examined.

T. Borvik et al. (2009) [28] studied the response of a steel container as closed structure under the blast loads. He used the mesh less methods based on the Lagrangian formulations to reduce mesh distortions and numerical advection errors to describe the propagation of blast load. All parts are modeled by shell element type in LS-DYNA. A methodology has been proposed for the creation of inflow properties in uncoupled and fully coupled Eulerian–Lagrangian LS-DYNA simulations of blast loaded structures.

TM 5-1300 (UFC 3-340-02) [29] is a manual titled "structures to resist the effects of accidental explosions" which provides guidance to designers, the step-to-step analysis and design procedure, including the information on such items

(1) Blast, fragment and shock loading.
(2) Principle on dynamic analysis.
(3) Reinforced and structural steel design and
(4) A number of special design considerations.

T. Ngo, et al. (2007) [30] for their study on "Blast loading and Blast Effects on Structures" gives an overview on the analysis and design of structures subjected to blast loads phenomenon for understanding the blast loads and dynamic response of various structural elements. This study helps for the design consideration against extreme events such as bomb blast, high velocity impacts.

III. RESEARCH SCOPE AND OBJECTIVES

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.

The foremost concern for blast-resistant design is human casualties due to structural collapse. The sources of dynamic excitation in a building under blast and earthquake loads are totally different in nature because blast loading is fast, localized and occurs at a much greater frequency than earthquake loading. However, there are some shared goals, In general, structures should be ductile enough to absorb the forces of an explosion without collapsing. Another comical element is the need for redundancy in structural design. Unlike seismic zones, however, buildings can resist blasts better with more mass. The energy of a blast is more easily absorbed by a more massive structure.

This qualifies reinforced concrete to be the principal material of choice for blast-resistant design. Generally the structures are not designed by considering blast charge because the cost of blast loading design and construction is very high. As a result, the structure is susceptible to damage from blast load. The explosion of bombs in and around buildings can cause catastrophic impacts on the structural integrity of the building, such as damage to the external and internal structural frames and collapse of walls. Moreover, loss of life can result from the collapse of the structure, direct blast effect, debris impact, fire and smoke. Some terrorist organizations have targeted buildings around the world. The consequences of those attacks proved the vulnerability of buildings to explosion. Many countries have become victims of bomb explosion attacks in the last decades. There are many deliberate explosion incidents that occurred in many different places such as the bombing of Alfred P. Murrah Federal Building, Khobar Towers Bombing, World Trade Center Bombing, among others. At the time of building design the consideration of performance of high-rise buildings under blast load is very important to protect such a high rise buildings from blast. Structures require a detailed understanding of explosives, blast phenomena and blast effects on buildings. One of the leading causes of injury following an explosion is flying shards of glass. Nadis recommends keeping window coverage to no more than 15 percent of wall area between supporting columns, Developments in laminated glass are producing stronger windows less prone to breaking into large pieces. Due to the limited budgets of many construction projects, the additional costs of buildings for providing blast resistance may apparently seem prohibitive. However, the average cost of designing for blast resistance in new structures is far less expensive than the cost to retrofit an existing structure to similar standards.

IV. PROPOSED WORK

Response of Building to Blast Loading

A detonation involves supersonic combustion of an explosive material and the formation of a shock wave. The three parameters that primarily determine the characteristics and intensity of blast loading are the weight of explosives, the type of the explosives, and the distance from the point of detonation to the protected building. These three parameters will primarily determine the characteristics and intensity of the blast loading. The distance of the protected building from the point of explosive detonation is commonly referred to as the stand-off distance.

For a specific type and weight of explosive material, the intensity of blast loading will depend on the distance and orientation of the blast waves relative to the protected space. For discussing the impact of blast loads on the buildings, the effects of explosion on the same have been classified in the following ways:

- Response due to blast outside the building
- Response due to internal blast within the building

BLAST OUTSIDE THE BUILDING

The explosive threat is particularly insidious, because all of the ingredients required to assemble an improvised explosive device are readily available at a variety of farm and hardware stores. The intensity of the explosive detonation is limited by the expertise of the person assembling the device and the means of delivery. Although the weight of the explosive depends on the means of transportation and delivery, the origin of the threat depends primarily on the access available to the perpetrator. In the design of buildings, the critical location at which the blast weapon must be considered is a function of site, building layout and security measures in place. The critical locations for external weapons (i.e., bombs in vehicle) are the closest points that a vehicle can approach the building on each of the sides of the perimeter, assuming that all security measures are in place. The stand-off distance is measured from the centre of gravity of the explosive located in a vehicle or container, to the building under consideration.

The onset of significant glass debris hazards is associated with stand-off distances on the order of hundreds of feet from a vehicle-borne explosive detonation while the onset of column failure is associated with stand-off distances on the order of tens of feet.

BLAST EFFECTS IN LOW-RISE BUILDINGS

Low-rise buildings may be vulnerable to blast loadings resulting from large weights of explosives at large standoff distances that may sweep over the top of the building. The blast pressures that may be applied to these roofs are likely to far exceed the conventional design loads and, unless the roof is a concrete deck or concrete slab structure, it may fail. The patterns of blast load intensity are complicated as the waves engulf the entire building. The pressures that load the roof, sides, and rear of the building are termed incident pressures, while the pressures that load the building envelope directly opposite the explosion are termed reflected pressures. Both the intensity of peak pressure and the impulse affect the hazard potential of the blast loading. In addition to the blast pressures that may be directly applied to the exterior columns and spandrel beams; the forces collected by the building envelope will be transferred through the slabs to the structural frame or shear walls that transfer lateral loads to the foundations. The extent of damage will be greatest in close proximity to the detonation; however, depending on the intensity of the blast, large inelastic deformations will extend throughout the building and cause widespread cracking to structural and non-structural partitions. In addition to the hazard of impact by building envelope debris propelled into the building or roof damage that may rain down, the occupants may also be vulnerable to much heavier debris resulting from structural damage. Progressive collapse occurs when an initiating localized failure causes adjoining members to be overloaded and fail, resulting in a cascading sequence of damage that is disproportionate to the originating extent of localized failure. The initiating localized failure may result from a sufficiently sized parcel bomb that is in contact with a critical structural element or from a vehicle sized bomb that is located a short distance from the building. However, a large explosive device at a large stand-off distance is not likely to selectively fail a single structural member; any damage that results from this scenario is more likely to be widespread and the ensuing collapse cannot be considered progressive. Although progressive collapse is not typically an issue for buildings three stories or shorter, transfer girders and non-ductile, non-redundant construction may produce structural systems that are not tolerant of localized damage conditions. The columns that support transfer girders and the transfer girders themselves may be critical to the stability of a large area of floor space.

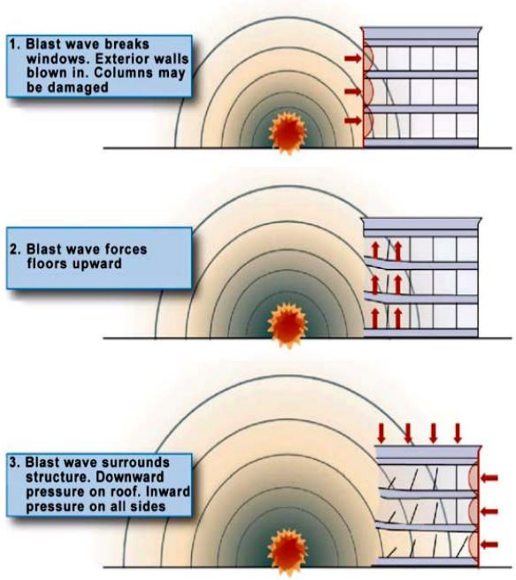

Fig 2: Schematic showing sequence of building damage due to a vehicle weapon from local damage to global damage due to progressive collapse (FEMA 427, 2003)[10]

As an example, panelised construction that is sufficiently tied together can resist the localized damage or large structural deformations that may result from an explosive detonation. This highlights the benefits of ductile and redundant detailing for all types of construction.

To mitigate the effects of in-structure shock that may result from the infilling of blast pressures through damaged enclosures, non-structural overhead items should be located below the raised floors or tied to the ceiling slabs with seismic restraints. Non-structural building components, such as piping, ducts, lighting units, and conduits must be sufficiently tied back to the building to prevent failure of the services and the hazard of falling debris.

BLAST EFFECTS IN HIGH-RISE BUILDINGS

High-rise buildings must resist significant gravity and lateral load effects; although the choice of framing system and specific structural details will determine the overall performance, the lower floors, which are in closest proximity to a vehicle-borne threat, are inherently robust and more likely to be resistant to blast loading than smaller buildings. However, tall buildings are likely to be located in dense urban environments that tend to trap the blast energy within the canyon like streets as the blast waves reflect off the neighbouring structures. Furthermore, tall buildings are likely to contain underground parking and loading docks that can introduce significant internal explosive threats. While these internal threats may be prevented through rigorous access control procedures, there are few conditions in which vehicular traffic can be restricted on city streets. Anti-ram streetscape elements are required to maintain a guaranteed stand-off distance from the face of the building.

In addition to the hazard of structural collapse, the facade is a much more fragile component. While the lower floor facade is likely to fail in response to a sizable vehicle threat at a sidewalk's distance from the building, the peak pressures and impulses at higher elevations diminish due to the increased stand-off distance and the associated shallow angle of incidence (measured with respect to the vertical height of the building). Although reflections of the neighbouring structures are likely to affect the intensity of blast loads, the facade loads at the upper floors will be considerably lower than the loads at the lower floors and the extent of facade debris will reflect this. A detailed building-specific analysis of the structure and the facade is required to identify the inherent strengths and vulnerabilities.

INTERNAL BLAST WITHIN THE BUILDING

When small hand-carried explosives are set off on floor slabs away from a primary vertical load-bearing element, local damage occurs along with injuries in the adjoining bays in each direction.

The damages associated with a small internal explosion in the building include:

- Local damage and failure of floor systems immediately below & above the explosion, and of adjoining walls (both RC and masonry)
- Damage and failure of nonstructural elements (e.g., partition walls, false ceilings, ducts and window finishes)
- Flying debris generated by furniture etc.

Severe damage, possibly leading to progressive collapse, may occur even with small internal explosions provided the explosive is placed directly at a primary load-bearing element such as a structural wall.

V. SIMULATION RESULTS

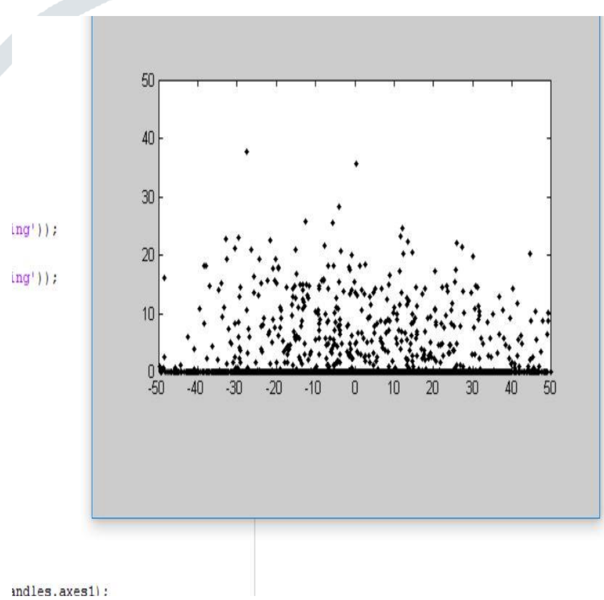

Fig 3- Blast Resistant Effect Case-I

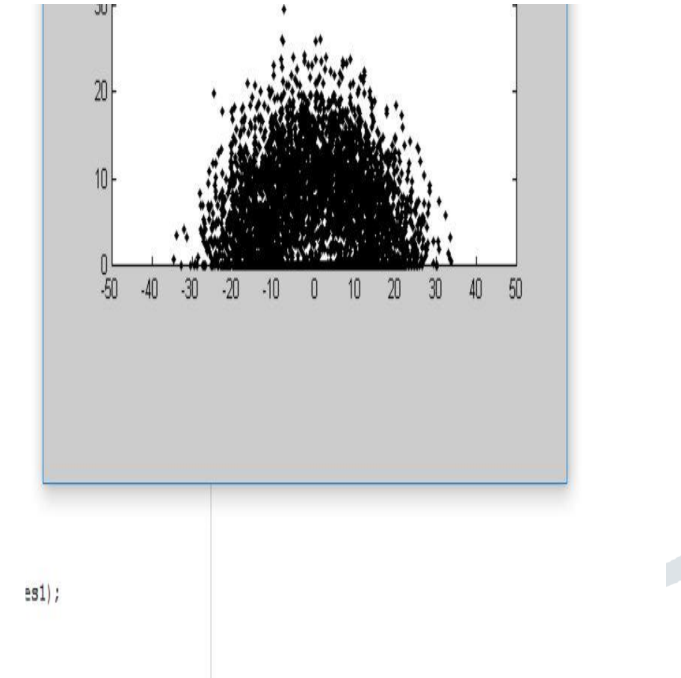

Fig 4- Blast Resistant Effect Case-II

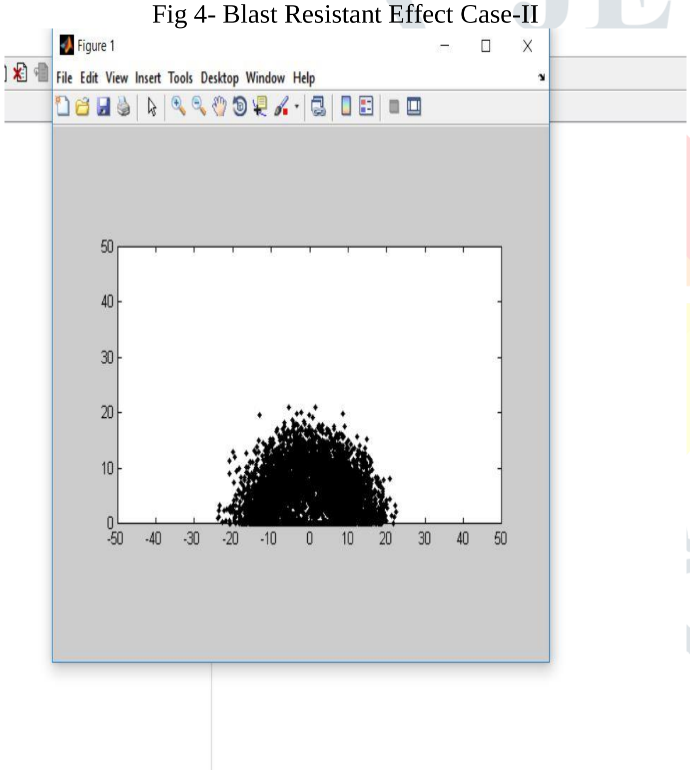

Fig 5- Blast Resistant Effect Case-III

VI. 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.

References

1. A.Khadid et al. (2007), “Blast loaded stiffened plates” Journal of Engineering and Applied Sciences,Vol. 2(2) pp. 456-461.
2. A.K. Pandey et al. (2006) “Non-linear response of reinforced concrete containment structure under blast loading” Nuclear Engineering and design 236. pp. 993-1002.
3. Alexander M. Remennikov, (2003) “A review of methods for predicting bomb blast effects on buildings”, Journal of battlefield technology, vol 6, no 3. pp 155-161.
4. American Society for Civil Engineers 7-02 (1997), “Combination of Loads”,pp 239-244.
5. Biggs, J.M. (1964), “Introduction to Structural Dynamics”, McGraw-Hill, New York.
6. Dannis M. McCann, Steven J. Smith (2007), “Resistance Design of Reinforced Concrete Structures”, STRUCTURE magazine, pp 22-27, April issue.
7. Demeter G. Fertis (1973), “Dynamics and Vibration of Structures”, A Wiley-Interscience publication, pp. 343-434.
8. D.L. Grote et al. (2001), “Dynamic behaviour of concrete at high strain rates and pressures”, Journal of Impact Engineering, Vol. 25, Pergamon Press, NewYork, pp. 869-886.
9. FEMA 426, Reference Manual to Mitigate Potential Terrorist Attacks against Buildings, Risk Management Series, Federal Emergency Management Agency, Department of Homeland Security, USA, December 2003
10. FEMA 427, Primer to Design Safe School Projects in Case of Terrorist Attacks, Risk Management Series, Federal Emergency Management Agency, Department of Homeland Security, USA, December 2003
11. FEMA 428, Primer to Design Safe School Projects in Case of Terrorist Attacks, Risk Management Series, Federal Emergency Management Agency, Department of Homeland Security, USA, December 2003
12. FEMA 429, Insurance, Finance and Regulation Primer for Terrorism Risk Management in Buildings, Risk Management Series, Federal Emergency Management Agency, Department of Homeland Security, USA, December 2003
13. FEMA 452, Risk Assessment - A How-To Guide to Mitigate Potential Terrorist Attacks Against Buildings, Risk Management Series, Federal Emergency

Management Agency, Department of Veterans Affairs, USA, January 2005

14. Glasstone S. and P.J. Dolan, 1977. The Effects of nuclear weapons. U.S. Government Publication.
15. IS 456:2000 Indian Standard Plain and Reinforced Concrete Code of Practice.
16. IITK GSDMA Guidelines on Measures to Mitigate Effects Of Terrorist Attacks On Buildings
17. J.M. Dewey (1971), “The Properties of Blast Waves Obtained from an analysis of the particle trajectories”, Proc. R. Soc. Lond. A.314, pp. 275-299.
18. J.M. Gere and S.P. Timoshenko (1997.), “Mechanics of materials”, PWS publishing company, Buston, Massachusetts,
19. Kirk A. Marchand, Farid Alfawakhiri (2005), “Blast and Progressive Collapse” fact for Steel Buildings, USA.
20. M. V. Dharaneepathy et al. (1995),“Critical distance for blast resistance design”, computer and structure Vol. 54, No.4.pp.587-595.
21. Nelson Lam et al. (2004), “Response Spectrum Solutions for Blast Loading”, Journal of Structural Engineering, pp 28-44.
22. P. Desayi and S. Krishnan (1964), “Equation for the stress-strain curve of concrete”. Journal of the American Concrete Institute, 61, pp 345-350.
23. S.Unnikrishna Pillai and Devdas Menon(2003), “Reinforced Concrete Design”, Tata McGraw-Hill.