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INTERNATIONAL JOURNAL FOR ENGINEERING APPLICATIONS AND TECHNOLOGY

REVIEW ON BLAST RESISTING STRUCTURE

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Abstract

Nowadays with growing technology, the structures are getting constructed in such a way that, it can resist the every second multiplying problem of terrorism including explosions or blast loads.

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. Initially, explosives and explosion types have been explained briefly. In accordance, the general aspects of explosion process have been presented to clarify the effects of explosives on buildings. To have a better understanding of explosives, 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 with different cases and examples .The analysis and design of structures subjected to blast loads require a detailed understanding of blast phenomena and the dynamic response of various structural elements. This paper presents a comprehensive overview of the effects of explosion on structures. An explanation of the nature of explosions and the mechanism of blast waves in analysed.

Index Terms*: Blast Resistant design, blast waves, explosive effects.*

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2. INTRODUCTION :

The main target of this study is to provide guidance to engineers and architects where there cis a necessity of protection against the explosions caused by detonation of high explosives. The guidance describes measures for mitigating the effects of explosions, therefore providing protection for human, structure and the valuable equipment inside. The paper includes information about explosives, blast loading parameters and enhancements for blast resistant building design both with an architectural and structural approach. Only explosions caused by high explosives (chemical reactions) are considered within the study. Explosive materials can be classified according to their physical state as solids, liquids or gases. Solid explosives are mainly high explosives for which blast effects are best known. They can also be classified on the basis of their sensitivity to ignition a secondary or primary explosive. The latter is one that can be easily detonated by simple ignition from a spark, flame or impact. Materials such as mercury fulminate and lead azide are primary explosives. Secondary explosives when detonated create blast (shock) waves which can result in widespread damage to the surroundings. Examples include **trinitrotoluene (TNT) and Ammonium nitrate/Fuel oil (ANFO).**

High explosives are solid in form and are commonly termed condensed explosives. TNT (trinitrotoluene) is the most widely known example. The main kind of explosion is unconfined explosion caused by explosives attached to the structure.

Unconfined explosions can occur as an **air-burst** or a **surface burst**. In an air burst explosion, the **detonation o**f the high explosive occurs above the ground level and intermediate amplification of the wave caused by ground reflections occurs prior to the arrival of the initial blast wave at a building (Figure 1) As the shock wave continues to propagate outwards along the ground surface, a front commonly called a Mach stem is formed by the interaction of the initial wave and the reflected wave.

However a surface burst explosion occurs when the detonation occurs close to or on the ground surface. The initial shock wave is reflected and amplified by the ground surface to produce a reflected wave. (Figure 2) Unlike the air burst, the reflected wave merges with the incident wave at the point of detonation and forms a single wave. In the majority of cases, terrorist activity occurs in built-up areas of cities, where devices are placed on or very near the ground surface.

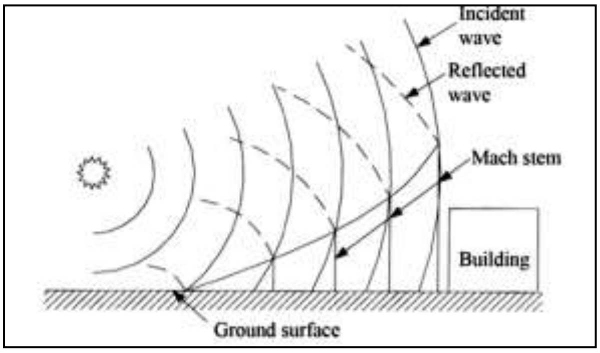

Figure1. Air burst with ground reflections

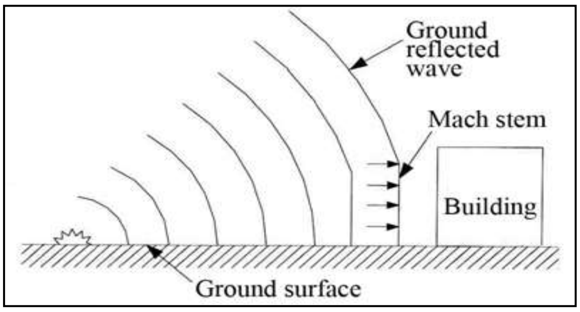

Figure 2. Surface burst

When an explosion occurs within a building, the pressures associated with the initial shock front will be high and therefore will be amplified by their reflections within the building. This type of explosion is called a confined explosion. In addition and depending on the degree of confinement, the effects of the high temperatures and accumulation of gaseous products produced by the chemical reaction involved in the explosion will cause additional pressures and increase the load duration within the structure. Depending on the extent of venting, various types of confined explosions are possible. (Figure 3)

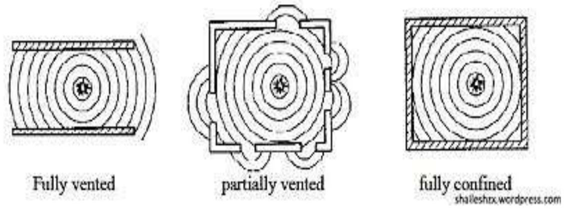

Figure 3. Fully vented, partially vented and fully confined explosions

If detonating explosive is in contact with a structural component, e.g. a column, the arrival of the detonation wave at the surface of the explosive will generate intense stress waves in the material and resulting crushing of the material. Except that an explosive in contact with a structure produces similar effects to those of unconfined or confined explosions.

There are many forms of high explosive available and as each explosive has its own detonation characteristics, the properties of each blast wave will be different. TNT is being used as the standard benchmark, where all explosions can be expressed in terms of an equivalent charge mass of TNT. The most common method of equalization is based on the ratio of an explosive's specific energy to that of TNT.

3. LITERATURE REVIEW:

- **Architectural and Structural Design of Blast Resisting Building:** Zeynep Koccaz[1] FatihSutcu[2] Necdet Torunbalci[3] (2008) :Essential techniques for increasing the capacity of a building to provide protection against explosive effects is discussed both with an architectural and structural approach.

- **Blast Loading and Blast Effects on Structures – An Overview:** T. Ngo[1], P. Mendis[2], A. Gupta[3]& J. Ramsay (2007)[4]: The analysis and design of structures subjected to blast loads require a detailed understanding of blast phenomena and the dynamic response of various structural elements. An explanation of the nature of explosions and the mechanism of blast waves in free air is given.

- **Blast Resistant Structure:** R. Logaraja (2014): 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.

- **Blast-Resistant Design of Structures:** Manmohan Dass Goel[1] and Vasant A. Matsagar[2]:In this paper, various strategies for blast mitigation are reviewed and discussed with an emphasis on presenting a comprehensive assessment of blast response mitigation technologies beginning from the necessary discussion on fundamental aspects of blast-induced impulsive loading and material characterization, especially at high strain rates.

3.1 CONCLUSION ON LITERATURE REVIEW:

- 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 centre is unquestionable.

- It is recommended that guidelines on abnormal load cases and provisions on progressive collapse prevention should be included in the current Building Regulations and Design Standards. Requirements on ductility levels also help improve the building performance under severe load conditions

- Blast resistant building design is to prevent the overall collapse of the building and fatal damages. In this context, architectural and structural design of buildings should be specially considered.

- The sacrificial blast wall provides a better solution and can be adopted or designed against an explosive induced threat. The various lightweight materials used for this purpose further add to increase blast resistance in comparison with conventional materials.

4. SEQUENCE OF TYPICAL BLAST EFFECT:

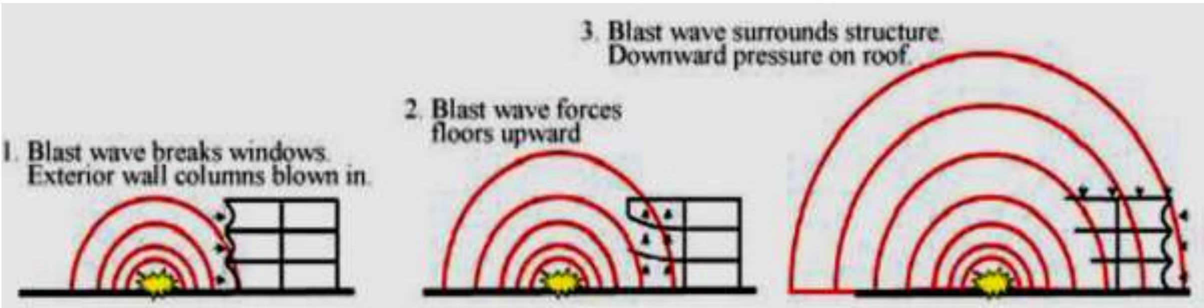

Figure 4: Sequence of typical blast effect

The initial shock wave is reflected and amplified by the ground surface to produce a reflected wave unlike the air burst, the reflected wave merges with the incident wave at the point of detonation and forms a single wave. In the majority of cases, terrorist activity occurs in built-up areas of cities, where devices are placed on or very near the ground surface.

5. EXAMPLES:

5.1 Oklahama Transport Bomb: On April 19, 1995, at 9:02 a.m. a forty-eight-hundred-pound ammonium nitrate–fuel oil bomb 2,300kg TNT exploded in a Ryder truck parked at the north entrance of the **Alfred P. Murrah Federal Building** in downtown Oklahoma City, killing 168 people and injuring approximately 850. The governor's office reported that thirty children were orphaned, 219 children lost at least one parent, 462 people were left homeless, and seven thousand people lost their workplace. The City of Oklahoma City's Final Report estimated property damage to more than three hundred buildings in a forty-eight-square-block area.

After blast big crater was created with **30 feet (9.1m) wide** and 8(2.4m)deep. Cladding and glasses of 258 buildings were broken resulting 5% of death by **glass debris** 652 thousand Dollar damage was held. The noise was heard up to 55miles i.e. 89km. The Seismic department caught this effect on Seismograph at **3.0** Richter scale.

Extensive rescue efforts were undertaken by local, state, federal, and worldwide agencies in the wake of the bombing, and substantial donations were received from across the country. The Federal Emergency Management Agency (FEMA) activated eleven of its Urban Search and Rescue Task Forces, consisting of 665 rescue workers who assisted in rescue and recovery operations.

Figure 5. Original Image of Federal Building after Blast.

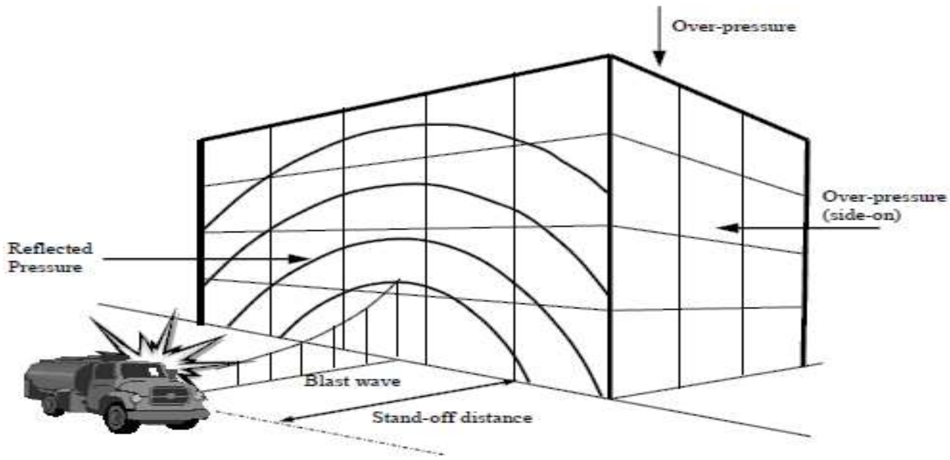

Figure 6. Conceptual Analysis

6.CASE STUDY: 1 RCC COLUMN SUBJECTED TO BLAST LOADING:

A ground floor column (6.4m high) of a multi-store building (modified from a typical building designed in Australia) was analyzed in this case study (see Fig. 7). The parameters considered were the concrete strength (40MPa for NSC column and 80 MPa for HSC column) and spacing of ligatures (400mm for ordinary detailing-OMRF and 100mm for special seismic detailing-SMRF). It has been found that with increasing concrete compressive strength, the column size can be effectively reduced. In this case the column size was reduced from 500 x 900 mm for the NSC

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column down to 350 x 750 for the HSC column while the axial load capacities of the two columns are still the same. The blast load was calculated based on data from the Oklahoma bombing report (ASCE 1996) with a standoff distance of 11.2m. The simplified triangle shape of the blast load profile was used. The duration of the positive phase of the blast is 1.3 milliseconds. The 3D model of the column (see Fig. 8) was analyzed using the nonlinear explicit code LS-Dyna 3D (2002) which takes into account both material nonlinearity and geometric nonlinearity. The strain rate- dependent constitutive model proposed in the previous section was adopted. The effects of the blast loading were modeled in the dynamic analysis to obtain the deflection time history of the column.

Column	Sizes	f'_c (MPa)	Ligature Spacing
NSC	500x900	40	400mm and 100mm
HSC	350x750	80	400mm and 100mm

Table 1: Concrete grades and Members Sizes

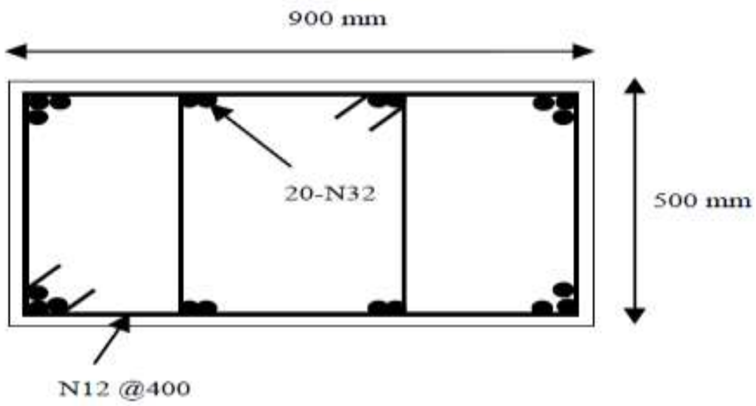
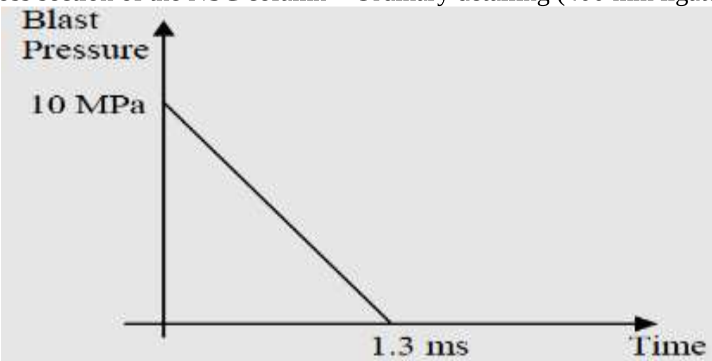


Figure 7. Cross section of the NSC column – Ordinary detailing (400 mm ligature spacing).



Graph1. Blast loading

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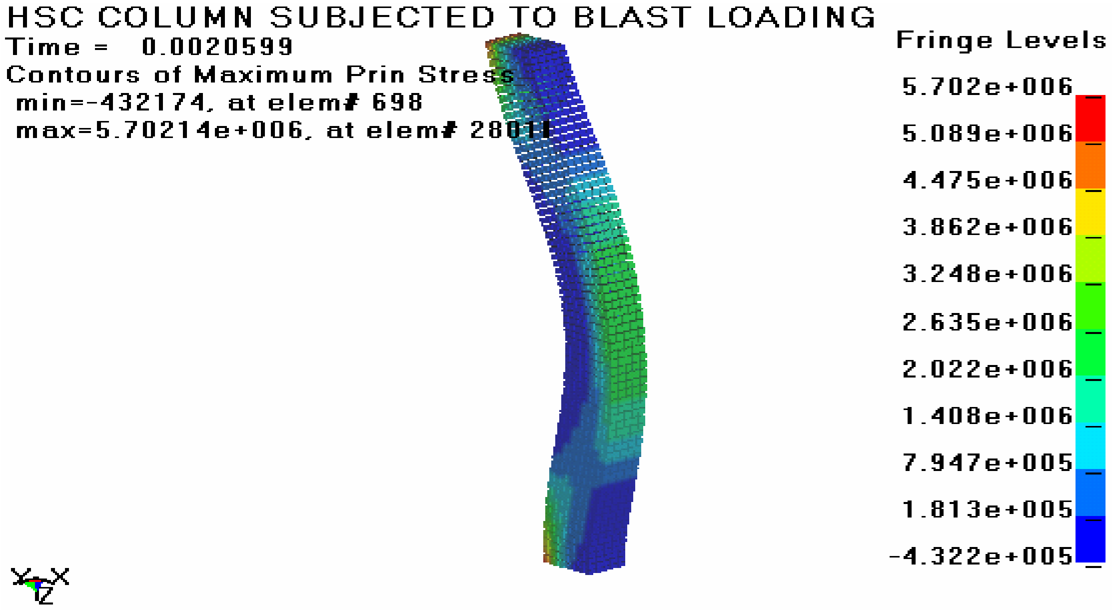
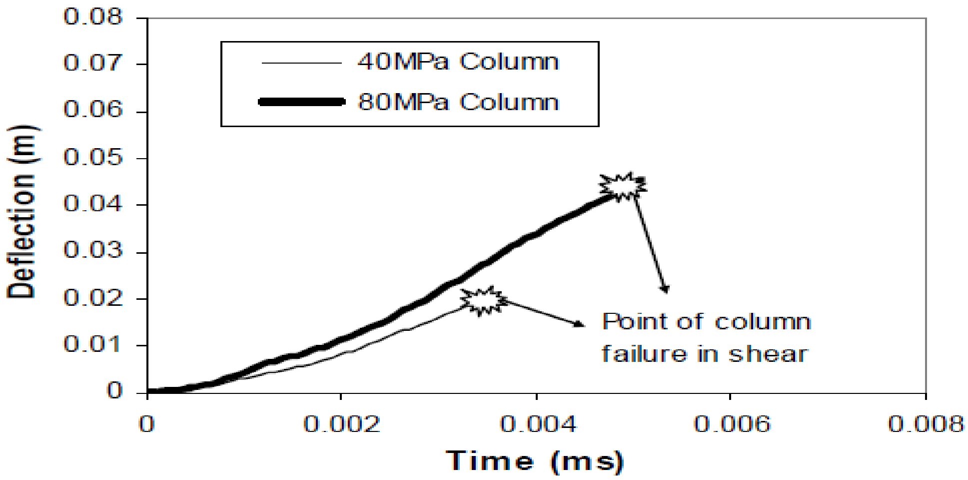


Figure 8. 3D model of the column using Explicit code LSDyna

6.1 RESULT AFTER BLAST LOADING:

The lateral deflection at midpoint versus time history of two columns made of NSC and HSC are shown in Graph 2and 3. The graphs clearly show the lateral resistance of the columns. It can be seen that under this close-range bomb blast both columns failed in shear. However, the 80MPa columns with reduced cross section have a higher lateral deflection, which shows a better energy absorption capacity compared to that of the 40 MPa columns (Graph 4 and Table 2). It can be seen from Graph 2 and 3 that the effect of shear reinforcement is also significant. The ultimate lateral displacements at failure increase from 45mm (400 mm ligature spacing) to 63mm (100mm ligature spacing) for the HSC column. Those values for the NSC column are 20mm and 32mm, respectively.



Graph 2. Lateral Deflection -Time history at midpoint of Column with 400mm ligature spacing

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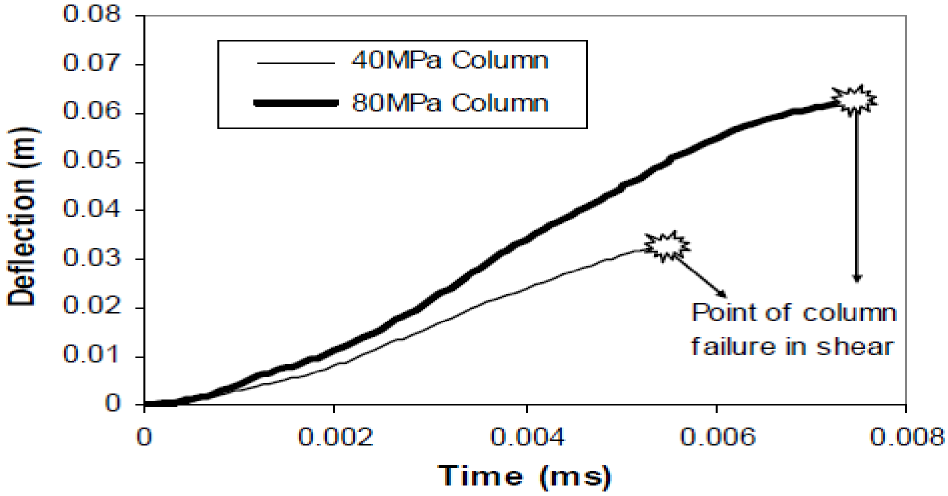
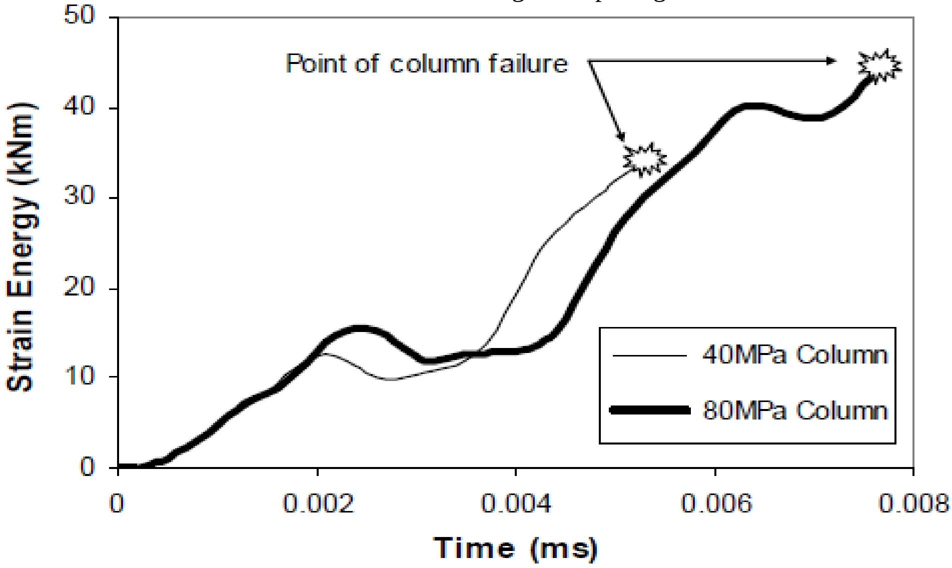


Graph 3. Lateral Deflection -Time history at midpoint of Column with 100mm ligature spacing.



Graph 4. Comparison of energy absorption capacities (100mm ligature spacing).

Column	400mm spacing	100mm spacing
NSC	12.0 kNm	33.9 kNm
HSC	27.6 kNm	43.5 kNm

Table 2. Energy absorptions at failure of HSC and NSC column

7.Case Study 2: DESIGN OF STEEL LOUVERS

Input data:

- Distance of explosive from louver: 70 m
- Blast charge: 1,000 lb
- Atmospheric temperature: 50° C
- Mach number: 1.085
- Material of louver: Grade-43 of BS4360

Structural analysis:

- Structural analysis for louvers involved transient response calculations

- Analysis based on procedure given in ASCE - Design of Blast Resistant Buildings in Petrochemical Facilities wherein the structure under consideration is transformed into an equivalent single degree of freedom (SDOF) system for dynamic response calculations
- Structural damping considered as zero

Results:

Support rotation and ductility ratio of the louvers are within acceptable limits. Hence, they can withstand the design blast loading

8.BUILDING RESPONSE TO BLAST LOAD:

1. W-R COMBINATION/ PSI TABLE:A full discussion and extensive charts for predicting blast pressures and blast durations are given by Mays and Smith (1995) and TM5-1300 (1990).Some representative numerical values of peak reflected over pressure are given in Table 3.

R \ W	100 kg TNT	500 kg TNT	1000 kg TNT
1m	165.8	354.5	464.5
2.5m	34.2	89.4	130.8
5m	6.65	24.8	39.5
10m	0.85	4.25	8.15
15m	0.27	1.25	2.53
20m	0.14	0.54	1.06
25m	0.09	0.29	0.55
30m	0.06	0.19	0.33

Table 3: Peak reflected overpressures *Pr* with different W-R Combinations

For design purposes, reflected overpressure can be idealized by an equivalent triangular pulse of maximum peak pressure *Pr* and time duration *td*, which yields the reflected impulse *ir*

Conclusion:

The structures in above case studies were analysed for blast loading using the SDOF approach. The design adequacy of these structural systems was checked by comparing the support rotations and ductility ratios obtained with the permissible specified. It was observed that the support rotation and ductility ratio induced in the structural systems were within the permissible limits and hence safe to withstand the pressure generated by the blast.

$$i_r = \frac{1}{2} P_r t_d$$

2 .DISTRUBUTION OF BLAST PRESSURE : When a terrorist bomb explodes in an urban area, air blast pressure typically fractures lightweight façades (see figure. 9)

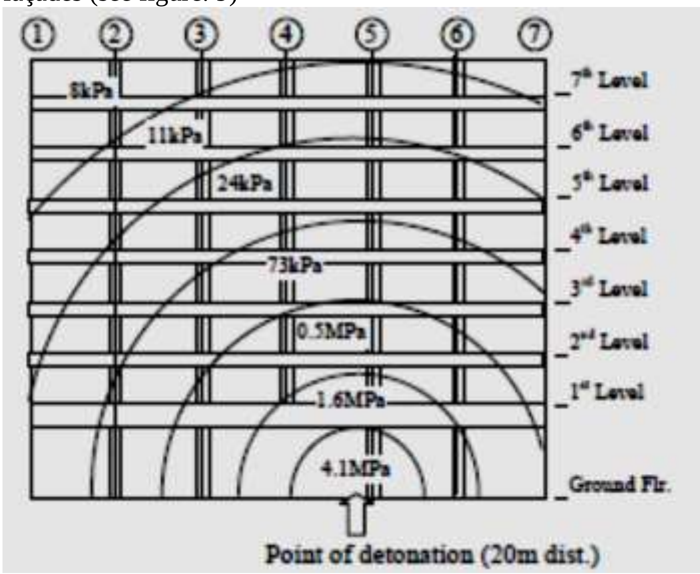


Fig. 9 Distribution of blast pressure on building façade (Mendis & Ngo, 2002)

Advanced computer codes such as **CFD** have been used to simulate the blast effects in the urban environment (Figs. 10). A typical tall building subjected to a bomb blast detonated at different stand-off distances from the ground level was analyzed in this study

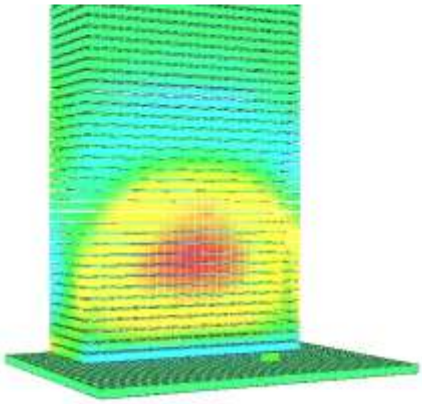
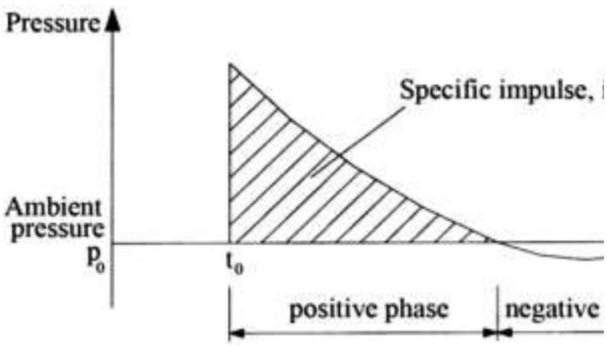


Fig. 10 CFD modelling of blast pressure on building structures
(Mendis & Ngo, 2002)

3. BLAST WAVE PRESSURE PLOTTED AGAINST TIME:



Graph 5. Pressure-Time graph

4. DAMAGE ON CERTAIN PSI:

Damage	Incident Overpressure (psi)
Typical window glass breakage	0.15 - 0.22
Minor damage to some buildings	0.5 - 1.1
Panels of sheet metal buckled	1.1 1.8
Failure of concrete block wall	1.8 - 2.9
Collapse of wood framed building	Over 5.0
Serious damage to steel framed buildings	4 -7
Severe damage to reinforced concrete structures	6 – 9
Probable total destruction of most buildings	10 - 12

Table 4: Damage Approximations (Kinney and Graham, 1985)

DIFFERENCE BETWEEN BLAST LOAD AND SEISMIC LOAD:

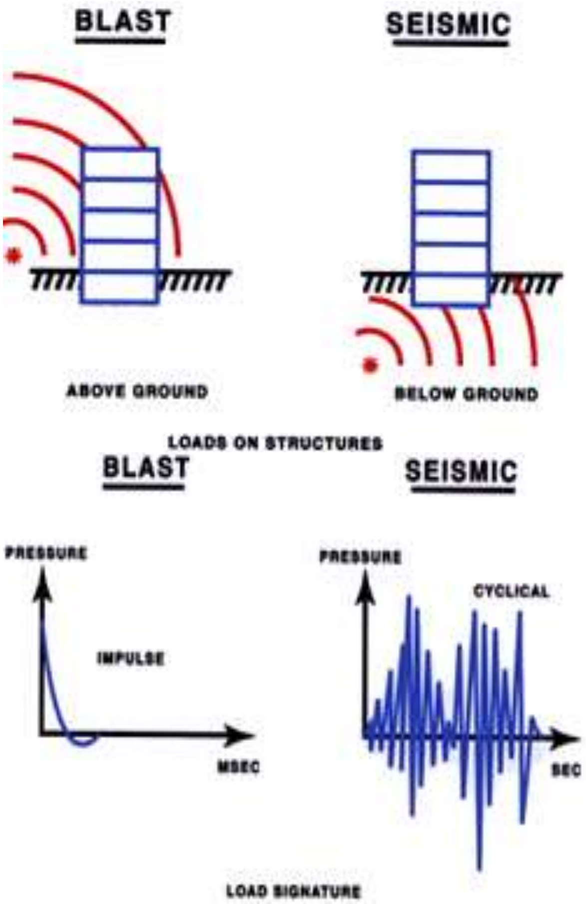


Figure 11: Blast load and Seismic load Comparison

9. DESIGN STRENTH OF BLAST RESISTING STRUCTURE:

1. **Reinforcing Steel:**
Dynamic yield stress 25 percent higher than the minimum specified static yield stress.

2. **Concrete:**
The dynamic cube compression strength may be assumed to be 25 percent higher than the minimum static cube strength at 28 days

3. **Design Stresses for Plain Concrete:**
The dynamic flexural strength of plain brick and stone masonry to be assumed to be the same at the corresponding static strength the compressive strength shall be taken 25% higher than the corresponding static strength .for unreinforced brick work the ductility ratio may be limited to 1.5 For reinforced brickwork, with not less than 0.05 percent steel on each face and not more than balanced percentage, the ductility factors as for reinforced concrete may be used.

4. **Bomb Proof Concrete:**
The material has a high cement content, low water/binder ratio and uses fine silica sand as its only aggregate. Short, straight steel fibers with a high compression and tensile strength in the region of 1,800 and 2,000N/mm2, respectively, reinforce the material.

5. **Paxcon: (Horizon Scope and Trade Pvt. Ltd) product,** for composite strength and combined strength of construction materials, specially on flying debris.

10. ARCHITECTURAL ASPECT:
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 regulations and the construction budget restrictions.

10.1.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. Figure 12 shows a possible external layout for blast safe planning.

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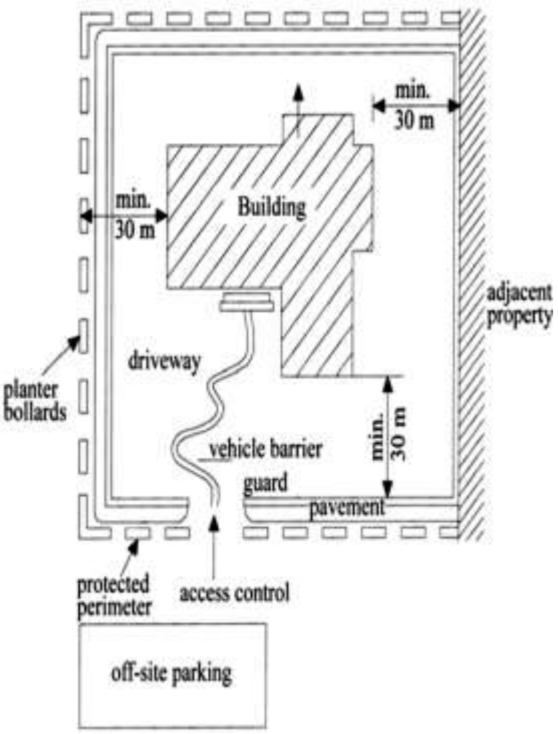

Figure12. Schematic layout of site for protection against bombs

10.2. BOMB SHELTER AREAS: The bomb shelter areas are specially designated within the building where vulnerability from the effects of the explosion is at a minimum and where personnel can retire in the event of a bomb threat warning. These areas must afford reasonable protection against explosions; ideally be large enough to accommodate the personnel involved and be located so as to facilitate continual access. For modern-framed buildings, shelter areas should be located away from windows, external doors, external walls and the top floors if the roof is weak. Areas surrounded by full-height concrete walls should be selected and underground car parks, gas storage tanks, areas light weight partition walls, e.g. internal corridors, toilet areas, or conference should be avoided while locating the shelter areas. Basements can sometimes be useful shelter areas, but it is important to ensure that the building does not collapse on top of them.

The functional aspects of a bomb shelter area should accommodate all the occupants of the building; provide adequate communication with outside; provide sufficient ventilation and sanitation; limit the blast pressure to less than the ear drum rupture pressure and provide alternative means of escape.

10.3.INSTALLATIONS: Gas, water, steam installations, electrical connections, elevators and water storage systems should be planned to resist any explosion affects. Installation connections are critical points to be considered and should be avoided to use in high-risk deformation areas. Areas with high damage receiving potential e.g. external walls, ceilings, roof

10.4.GLAZING AND CLADDING: Glass from broken and shattered windows could be responsible for a large number of injuries caused by an explosion in a city centre. The choice of a safer glazing material is critical and it has been found out that laminated glass is the most effective in this context. On the other hand, applying transparent polyester anti-shatter film to the inner surface of the glazing is as well an effective method.

For the cladding, several aspects of design should be considered to minimize the vulnerability of people within the building and damage to the building itself. The amount of glazing in the facade should be minimized. This will limit the amount of internal damage from the glazing and the amount of blast that can enter. It should also be ensured that the cladding is fixed to the structure securely with easily accessible fixings. This will allow rapid inspection after an explosion so that any failure or movement can be detected.

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11. ECONOMICAL BUT A SAFE STRUCTURE AGAINST BLAST LOAD: By ***ManmohanDass Goel[1]****and* ***Vasant A. Matsagar[2]*****(**Blast-Resistant Design of Structures)

A **Sacrificial blast wall** is a protection barricade that protects a target structure from an explosion. An explosion produces a blast load that impinges on the structure, and the wall acts as a mitigation measure. The main function of the wall is to keep the energy imparted by the explosion from reaching the structure to be protected. The important requirement for mitigating the blast-imparted energy is that the wall may be damaged permanently, but the structure should be safe and functioning well after the blast. This paves the way for the wall being lightweight and able to deform to a large extent, thus absorbing a large amount of energy. Based on past investigations, it is observed that the surface of the wall facing the explosion source should be vertical as far as possible (Smith2010). However, when the wall top has a canopy or overhang, it results in marginal improvement of mitigation capacity as reported by Smith (2010). It is well established that increased standoff distance is the best mitigation measure, which is further supplemented by the presence of a sacrificial blast wall helping reduce energy imparted on the target structure. Shows some of the design considerations for a sacrificial blast wall, and shows the formation of Mach stem and triple point. Mach stem is a region of high overpressure due to coalescence of incident and reflected wave at some point above ground. It is to be noted that the design of the wall and approach to it should be such that no explosion results in formation of the Mach stem. This aspect should be considered in the design of the sacrificial blast wall as well as blast-resistant structures. Fig. 13shows the typical details of the sacrificial blast wall. The energy-absorbing material (such as metal foams, polymeric foams, and similar) is sandwiched between two stiffer layers to enhance the protection against blast-induced impulsive loading. When the wall is subjected to impulsive loading, most of the energy imparted by the blast is absorbed by the soft sandwiched material in plastic deformation, and a very small amount of deformation is experienced by the parent structure protected behind it. It is possible that the sacrificial blast wall is provided as camouflage within peripheral compound walls, backs of benches, etc. Especially, in populated cities, it may not be possible to adopt the strategies that require space response teams), blast protection and mitigation can be enhanced (Ettouney et al. 1996; Crawford 2006; Naito and Wheaton 2006;Longinow 2008; Pape et al. 2010a, b, c). Protection is further supplemented by hardening measures including designing blast resistant columns, walls, and windows. Shows various measures that can be modified and altered per the actual site and threat level requirements.

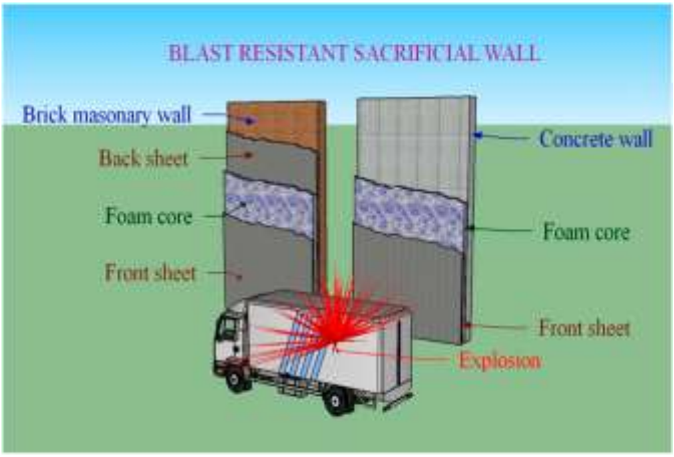

Fig. 13. Typical layout of sacrificial blast wall

12. CONCLUSION:

For high-risks facilities such as public and commercial tall buildings, design considerations against extreme events (bomb blast, high velocity impact) is very important. It is recommended that guidelines on abnormal load cases and provisions on progressive collapse prevention should be included in the current Building Regulations and Design Standards. Requirements on ductility levels also help improve the building performance under severe load conditions. 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.

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 design, 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

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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; it's 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.

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