Prediction of Blast Loading And Its Impact on Buildings

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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.

The response of simple RC columns subjected to constant axial loads and lateral blast loads was examined. The finite element package ANSYS was used to model RC column with different boundary conditions and using the mesh less method to reduce mesh distortions. For the response calculations, a constant axial force was first applied to the column and the equilibrium state was determined. Next, a short duration, lateral blast load was applied and the response time history was calculated.

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 gives a comprehensive overview of the effects of explosion on structures.

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.

Due to different accidental or intentional events, the behavior of structural components subjected to blast loading has been the subject of considerable research effort in recent years. Conventional structures, particularly that above grade, normally are not designed to resist blast loads; and because the magnitudes of design loads are significantly lower than those produced by most explosions, conventional structures are susceptible to damage from explosions. With this in mind, developers, architects and engineers increasingly are seeking solutions for potential blast situations, to protect building occupants and the structures.

Disasters such as the terrorist bombings of the U.S. embassies in Nairobi, Kenya and Dar es Salaam, Tanzania in 1998, the Khobar Towers military barracks in Dhahran, Saudi Arabia in 1996, the Murrah Federal Building in Oklahoma City in 1995, and the World Trade Center in New York in 1993 have demonstrated the need for a thorough examination of the behavior of columns subjected to blast loads. To provide adequate protection against explosions, the design and construction of public buildings are receiving renewed attention of structural engineers. Difficulties that arise with the complexity of the problem, which involves time dependent finite deformations, high strain rates, and non-linear inelastic material behavior, have motivated various assumptions and approximations to simplify the models. These models span the full range of sophistication from single degree of freedom systems to general purpose finite element programs such as ABAQUS, ANSYS, and ADINA etc. [1].

II. REVIEW OF LITERATURE

GENERAL

The analysis of the blast loading on the structure started in 1960's. US Department of the Army, released a technical manual titled "structures to resist the effects of accidental explosions" in 1959. The revised edition of the manual TM 5-1300 (1990) most widely used by military and civilian organization for designing structures to prevent the propagation of explosion and to provide protection for personnel and valuable equipments.

The methods available for prediction of blast effects on buildings structures are:

- Empirical (or analytical) methods
- Semi-empirical methods
- Numerical methods.

Empirical methods are essentially correlations with experimental data. Most of these approaches are limited by the extent of the underlying experimental database. The accuracy of all empirical equations diminishes as the explosive event becomes increasingly near field.

Semi-empirical methods are based on simplified models of physical phenomena. The attempt is to model the underlying important physical processes in a simplified way. These methods are dependent on extensive data and case study. The predictive accuracy is generally better than that provided by the empirical methods.

Numerical (or first-principle) methods are based on mathematical equations that describe the basic laws of physics governing a problem. These principles include conservation of mass, momentum, and energy. In addition, the physical behavior of materials is described by constitutive relationships. These models are commonly termed computational fluid dynamics (CFD) models.

The key elements are the loads produced from explosive sources, how they interact with structures and the way structures respond to them. Explosive sources include gas, high explosives, dust and nuclear materials. The basic features of the explosion and blast wave phenomena are presented along with a discussion of TNT (trinitrotoluene) equivalency and blast scaling laws. The characteristics of incident overpressure loading due to atomic weapons, conventional high explosives and unconfined vapors cloud explosions are addressed and followed by a description of the other blast loading components associated with air flow and reflection process. Fertice G. [8] has extensive study of the structures and computation of blast loading on aboveground structures.

A. Khadid et al. [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. [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 non- linear analysis by adopting the above model has been implemented into a finite element code DYNAIB.

III. OBJECTIVE AND SCOPE OF THE PRESENT WORK OBJECTIVE

For analyse and design the structures against the abnormal loading conditions like blast loads, strong wind pressure etc. requiring detailed understanding of blast phenomenon.

To study the dynamic response of various structural elements like column, beam, slab and connections in steel and RCC structures.

The main objective of the research presented in this thesis is to analytically and numerically study the structural behavior of HSC and NSC column subjected to blast loading.

IV. SCOPE OF THE STUDY

In order to achieve the above-mentioned objectives the following tasks have been carriedout:

All the computation of dynamic loading on a rectangular structure with and without openings and open frame structures to evaluate the blast pressure.
Computation of the blast loading on the column.

Modeling of a simple RC column in ANSYS.Response of a simple RC column under the Blast loading.

V. BACKGROUND

EXPLOSION AND BLAST PHENOMENON

In general, an explosion is the result of a very rapid release of large amounts of energy within a limited space.

Explosions can be categorized on the basis of their nature as physical, nuclear and chemical events.

In physical explosion: - Energy may be released from the catastrophic failure of a cylinder of a compressed gas, volcanic eruption or even mixing of two liquid at different temperature.

In nuclear explosion: - Energy is released from the formation of different atomic nuclei by the redistribution of the protons and neutrons within the inner acting nuclei.

In chemical explosion: - The rapid oxidation of the fuel elements (carbon and hydrogen atoms) is the main source of energy.

The type of burst mainly classified as

- Air burst
- High altitude burst
- Under water burst
- Underground burst
- Surface burst

The discussion in this section is limited to air burst or surface burst. This information is then used to determine the dynamic loads on surface structures that are subjected to such blast pressures and to design them accordingly. It should be pointed out that surface structure cannot be protected from a direct hit by a nuclear bomb; it can however, be designed to resist the blast pressures when it is located at some distance from the point of burst.

The destructive action of nuclear weapon is much more severe than that of a conventional weapon and is due to blast or shock. In a typical air burst at an altitude below 100,000 ft. an approximate distribution of energy would consist of 50% blast and shock, 35% thermal radiation, 10% residual nuclear radiation and 5% initial nuclear radiation [8].

The sudden release of energy initiates a pressure wave in the surrounding medium, known as a shock wave as shown in Fig.1 (a). When an explosion takes place, the expansion of the hot gases produces a pressure wave in the surrounding air. As this wave moves away from the centre of explosion, the inner part moves through the region that was previously compressed and is now heated by the leading part of the wave. As the pressure waves moves with thevelocity of sound, the temperature is about 3000o-4000oC and the pressure is nearly 300 kilobarof the air causing this velocity to increase. The inner part of the wave starts to move faster and gradually overtakes the leading part of the waves. After a short period of time the pressure wave front becomes abrupt, thus forming a shock front some what similar to Fig 1 (b). The maximum overpressure occurs at the shock front and is called the peak overpressure. Behind the shock front, the overpressure drops very rapidly to about one-half the peak overpressure and remains almost uniform in the central region of the explosion.

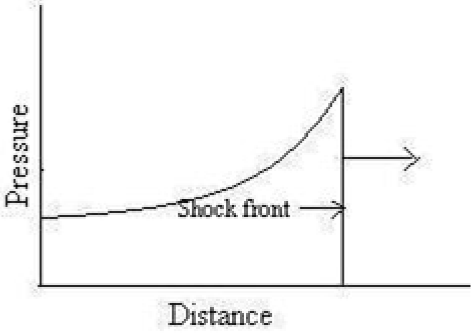


Fig. 1 (a) Variation of pressure with distance

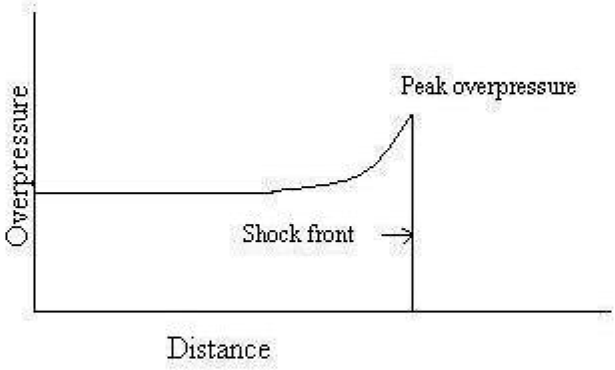


Fig 1 (b) Formation of shock front in a shock wave

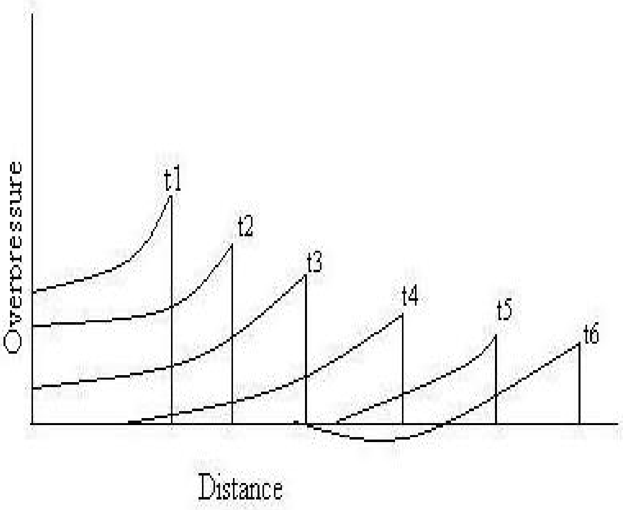


Fig 1 (c) Variation of overpressure with distance from centre of explosion at various times.

An expansion proceeds, the overpressure in the shock front decreases steadily; the pressure behind the front does not remain constant, but instead, fall off in a regular manner. After a short time, at a certain distance from the centre of explosion, the pressure behind the shock front becomes smaller than that of the surrounding atmosphere and so called negative-phase or suction.

The front of the blast waves weakens as it progresses outward, and its velocity drops towards the velocity of the sound in the undisturbed atmosphere. This sequence of events is shown in Fig 1(c), the overpressure at time t1, t2…..t6 are indicated. In the curves marked t1 to t5, the pressure in the blast has not fallen below that of the atmosphere. In the curve t6 at some distance behind the shock front, the overpressure becomes negative. This is better illustrated in Fig .2 (a).

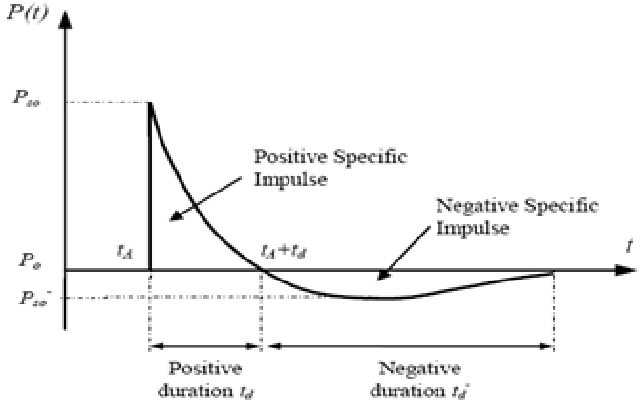


Fig.2 (a) The variation of overpressure with distance at a given time from centre of explosion.

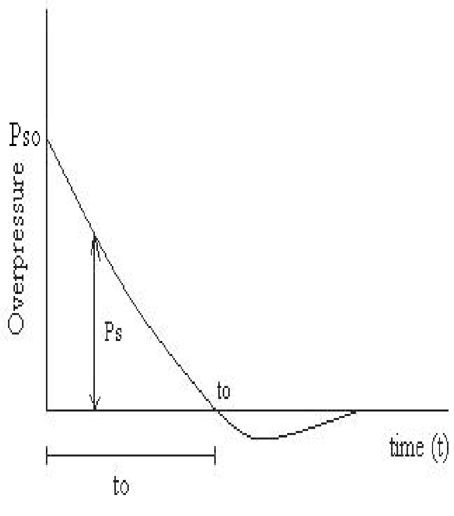


Fig2 (b) Variation of overpressure with distance at a time from the explosion.

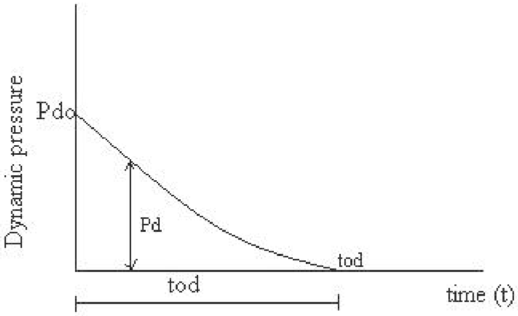


Fig 2(c) Variation of dynamic pressure with distance at a time from the explosion

The time variation of the same blast wave at a given distance from the explosion is shown in Fig.2(b); to indicate the time duration of the positive phase and also the time at the end of the positive phase. Another quantity of the equivalent importance is the force that is developed from the strong winds accompanying the blast wave known as the dynamic pressure; this is proportional to the square of the wind velocity and the density of the air behind the shock front. Its variation at a given distance from the explosion is shown in Fig. 2(c).

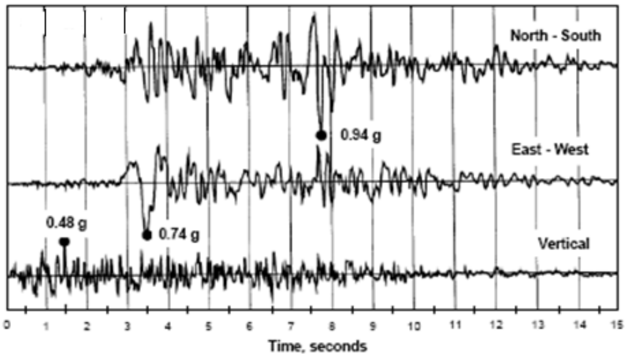
Explosive and impact loads similar to and different from loads typically used in building design.

Explosive loads and impact loads are transients, or loads that are applied dynamically as one-half cycle of high amplitude, short duration air blast or contact and energy transfer related pulse. This transient load is applied only for a specific and typically short period of time in the case of blast loads, typically less than one-tenth of a second [13]. This means that an additional set of dynamic structural properties not typically considered by the designer, such as rate dependant material properties and inertial effects must be considered in design

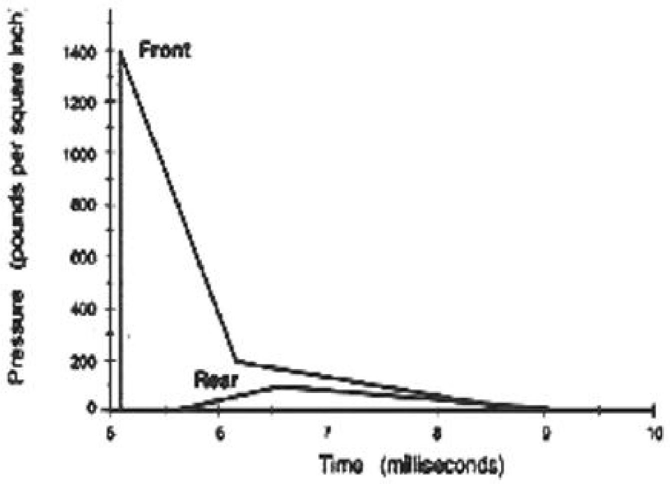
How blast loads are different from seismic loads.

Blast loads are applied over a significantly shorter period of time (orders-of-magnitude shorter) than seismic loads. Thus, material strain rate effects become critical and must be accounted for in predicting connection performance for short duration loadings such as blast. Also, blast loads generally will be applied to a structure non-uniformly, i.e., there will be a variation of load amplitude across the face of the building, and dramatically reduced blast loads on the sides and rear of the building away from the blast. Figure 3 shows a general comparison between an acceleration record from a point 7 km from the 1994 Northridge epicenter and the predicted column loads for the 1995 Oklahoma City bombing [13].

It is apparent that the 12-second-long ground shaking from the Northridge event lasted approximately 1000 times longer than the 9 ms initial blast pulse from the Murrah Building blast. The effects of blast loads are generally local, leading to locally severe damage or failure. Conversely, seismic “loads” are ground motions applied uniformly across the base or foundation of a structure. All components in the structure are subjected to the “shaking” associated with this motion.



(a)Response of seismic loading onstructure



(b)Response of blast loading on structure.

Fig.3 Comparison between seismic load and the blast load

VI. EXPLOSIVE AIR BLAST LOADING

The threat for a conventional bomb is defined by two equally important elements, the bomb size, or charge weight W, and the standoff distance (R) between the blast source and the target (Fig.4). For example, the blast occurred at the basement of World Trade Centre in 1993 has the charge weight of 816.5 kg TNT. The Oklahoma bomb in 1995 has a charge weight of 1814 kg at a stand off of 5m [13]. As terrorist attacks may range from the small letter bomb to the gigantic truck bomb as experienced in Oklahoma City, the mechanics of a conventional explosion and their effects on a target must be addressed.

Throughout the pressure-time profile, two main phases can be observed; portion above ambient is called positive phase of duration (td), while that below ambient is called negative phase of duration (td). The negative phase is of a longer duration and a lower intensity than the positive duration. As the stand-off distance increases, the duration of the positive-phase blast wave increases resulting in a lower-amplitude, longer-duration shock pulse. 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. 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. During the negative phase, the weakened structure may be subjected to impact by debris that may cause additional damage.

STAND-OFF DISTANCE

Stand-off distance refers to the direct, unobstructed distance between a weapon and its target. HEIGHT OF BURST (HOB)Height of burst refers to aerial attacks. It is the direct distance between the exploding weapon in the air and the target

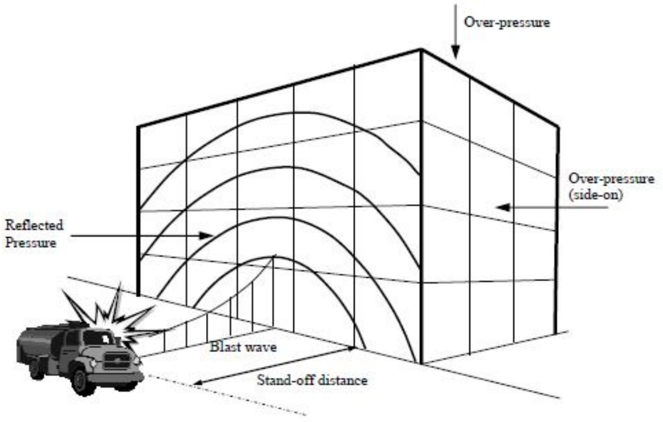


Figure 4: Blast Loads on a Building.

STRUCTURAL RESPONSE TO BLAST LOADING

Complexity in analyzing the dynamic response of blast-loaded structures involves the effect of high strain rates, the non-linear inelastic material behavior, the uncertainties of blast load calculations and the time-dependent deformations. Therefore, to simplify the analysis, a number of assumptions related to the response of structures and the loads has been proposed and widely accepted. To establish the principles of this analysis, the structure is idealized as a single degree of freedom (SDOF) system and the link between the positive duration of the blast load and the natural period of vibration of the structure is established.

VII. MATERIAL BEHAVIORS AT HIGH STRAIN RATE

Blast loads typically produce very high strain rates in the range of 102 - 104 s-1. This high loading rate would alter the dynamic mechanical properties of target structures and, accordingly, the expected damage mechanisms for various structural elements. For reinforced concrete structures subjected to blast effects the strength of concrete and steel reinforcing bars can increase significantly due to strain rate effects. Figure 5 shows the approximate ranges of the expected strain rates for different loading conditions. It can be seen that ordinary static strain rate is located in the range: 10-6-10-5 s-1, while blast pressures normally yield loads associated with strain rates in the range: 102-104 s-1.

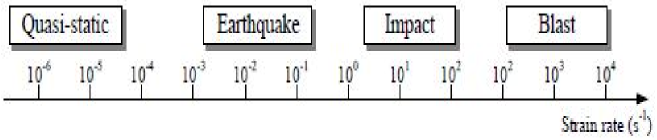


Figure 5 Strain rates associated with different types of loading

VIII. RESULTS AND DISCUSSION

RC COLUMN SUBJECTED TO BLAST LOADING

A ground floor column 6.4m high of a multi-storey building was analyzed in this study (see table 6.1). The parameters considered were the concrete strength 40MPa for Normal strength column(NSC) and 80 MPa for High strength column(HSC) and stirrups spacing is 400mm for ordinary detailing and 100mm for special seismic detailing. 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 column down to 350 x 750 for the HSC column details given in figure 6.1, 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 [13] with a stand off distance of 5 m. The simplified triangle shape of the blast load profile was used (see Table 1). The duration of the positive phase of the blast is 1.3 milliseconds.

Table 1 Concrete grades and member size.

Column	Sizes	Grade of concrete(*fck*)	Stirrups spacing	Detailing
NSC	500x 900	40 N/mm^2	400mm	ordinary
NSC	500x 900	40 N/mm^2	100mm	seismic
HSC	350x 750	80 N/mm^2	400mm	ordinary
HSC	350x 750	80 N/mm^2	100mm	seismic

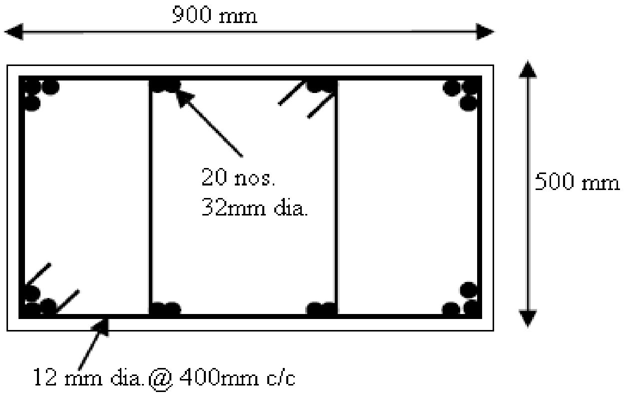


Figure 6.1 Cross section of the NSC column- ordinary detailing 400 mm stirrups spacing

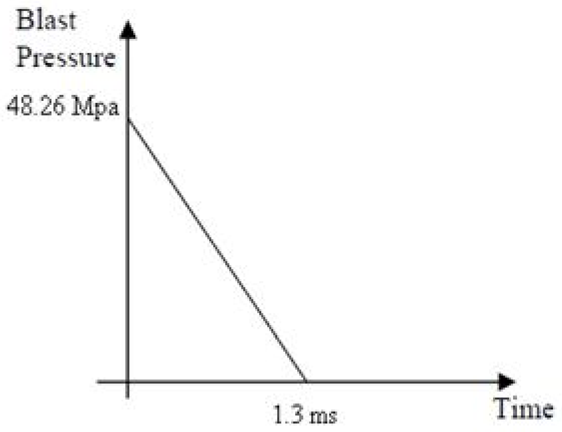


Figure 6.2 Blast loading

The lateral deflection at mid point versus time history of two columns made of NSC and HSC are shown in Figs.6.3 and 6.4 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.

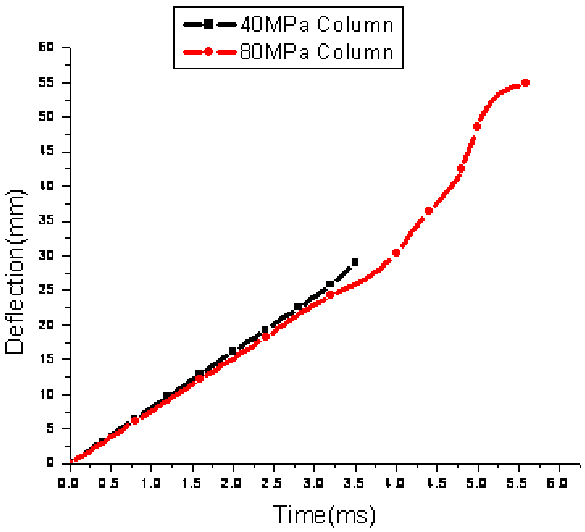


Figure 6.3 Lateral Deflection – Time history at mid point of column with 400 mm stirrups spacing.

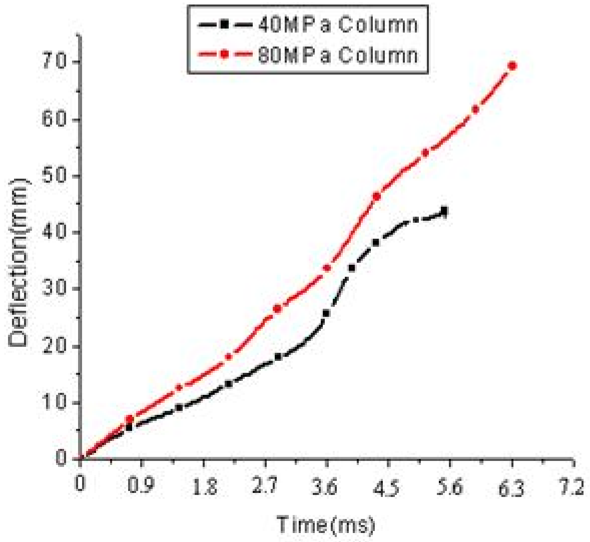


Figure 6.4, Lateral Deflection – Time history at mid point of column with 100 mm stirrups spacing

It can be seen from Figs.6.3 and 6.4 that the effect of shear reinforcement is also significant. The ultimate lateral displacements at failure increase from 54 mm (400 mm stirrups spacing) to 69 mm (100 mm stirrups spacing) for the HSC column. Those values for the NSC column are 29mm (400 mm stirrups spacing) and 43 mm (100 mm stirrups spacing), respectively.

Table 2 Comparison of the lateral deflection at mid point of HSC and NSC columns.

Column	Sizes	Grade of concrete(f_{ck})	Stirrups spacing	Detailing
NSC	500x900	40 N/mm^2	400mm	ordinary
NSC	500x900	40 N/mm^2	100mm	seismic
HSC	350x750	80 N/mm^2	400mm	ordinary
HSC	350x750	80 N/mm^2	100mm	seismic

XI. CONCLUSIONS

Based on the studies available in the literature, the ultimate objective is to make available the procedure for calculating the blast loads on the structures with or without the openings and frame structures. Also to study the dynamic properties of reinforcing steel and concrete under high strain rates typically produce by the blast loads. From this part of the study, an understanding of how reinforced concrete columns respond to blast loads was obtained.

The following observations and conclusions are drawn from this studyThe finite element analysis revealed that, for axially loaded columns, there exists a critical lateral blast impulse. Any applied blast impulse above this value will result in the collapsing of the column before the allowable beam deflection criterion is reached.

The column response to non-uniform blast loads was shown to be significantly influenced by higher vibration modes. This was especially true for the unsymmetrical blast loads.

The comparison between the normal strength column and the higher strength column showed that the critical impulse for the higher strength column case is significantly higher. This increase can be attributed to the added stiffness.

The surfaces of the structure subjected to the direct blast pressures can not be protected; it can, however, be designed to resist the blast pressures by increasing the stand-off distance from the point of burst.

FUTURE SCOPE OF STUDY

Cases in which the axial load does not remain constant during the column response time are possible. These include situations where the bomb is located within the structure and the blast excites the girders connected to the column. The effect of this time-varying axial load should be studied.

Cases should be studied when the explosions within a structure can cause failure of interior girders, beams and floor slabs.

Tests and evaluation of connections under direct blast loads.Tests and design recommendations for base plate configurations and designs to resist direct shear failure at column bases.

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