Nonlinear Dynamic Analysis of High Rise Building Subjected To Air and Ground Blast

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Abstract: In recent decades, use of vehicle bombs and air attacks to destroy nationally important buildings in a city has become a distinct signature of various terrorist organizations around the world. A bomb explosion not only damages the structural frame of the building but also results in collapsing of walls, flying debris, breaking glasses, thus threatening human life. Due to such threats, now a day's efforts are made to develop methods for analysis and design of high importance buildings to resist blast loads. This study is about nonlinear analysis and design of typical tall building under blast loading. In this study, a G+45 reinforced concrete building is analyzed for a blast equivalent of 500 kg of TNT at ground standoff of – 30m, 40m and 50m. The same building is analyzed for air blast of same intensity at 8th, 23rd and 38th floor at 30m standoff distance. Also, the orientation of blast at 45° is proposed other than the perpendicular direction. Response of blast excited building is studied and reviewed for 500kg of TNT placed on ground and in the air. The review mainly emphases on nonlinear dynamic response and performance level of building under various positions of blast loads. The blast load is calculated IS 4991-1968 criteria for blast resistant design of structures for above ground explosions. The key observation was blast effect decreases as standoff distance increases and the nonlinear dynamic response was decreased. Noteworthy outcome of the study was building performance level is critical when the standoff distance is reduced. For various heights of blast source, more blast force is generated when explosion was at 23rd floor and 30m ground distance because in this case blast force will be more above and below. The dynamic response of a building is unsystematic and not concentrated at top storey.

Keywords: Bomb Explosion, Blast Load, Attack, Dynamic Response, Standoff Distance

I. INTRODUCTION

Rising alone above the crowd has always held a special thrill. Every country is trying its best to leave a mark on the map of world by constructing High rise structures. The growth in modern multistoried building construction, which began in late 19th century, is intended largely for commercial and residential purposes. The development of the high-rise building has followed the growth of the city closely. Recent history suggests if the building is tall it will attract more attention from terrorist, that's why the design and construction of high rise building, to provide life safety in the face of explosion is receiving renewed attention from engineers. The threat of terrorism is increasing in major cities of the world, e.g. 9/11 attacks in New York and vehicle bombing in Oklahoma City (USA),

Under all such circumstances it becomes necessary to study the effect of high rise building subjected to blast load. In the recent past terrorist have used explosive laden vehicles and aircrafts and those

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are used for striking the targets, thereby causing the damage and destruction to the life and property. Structures may experience blast loads due to military actions, accidental explosions or terrorist activities. Such load may cause severe damage or collapse due to their high intensity, dynamic nature, and usually different direction compared to common design loads. Collapse of one structural member near the source of explosion, may then create critical stress redistributions and lead to collapse of other members, and eventually of the whole structure. There are numerous texts, guides and manuals on the subject, with continuing research and technical reporting occurring at a brisk pace.

When an explosion takes place, an exothermic chemical reaction occurs in a period of few milliseconds. The explosive material (in either solid or liquid form) is converted to very hot, dense, high-pressure gas. This highly compressed air, traveling radially outward from the source at supersonic velocities is called the shock wave front. It expands at very high speeds and eventually reaches equilibrium with the surrounding air. Thus, a blast causes an almost instantaneous rise in air pressure from atmospheric pressure to a large overpressure. As the shock front expands, the pressure drops but becomes negative as shown in Figure 1. Usually, this negative pressure is sustained for a duration longer than the positive pressure, and is less important in design of structures than the positive phase [1]. The magnitude and distribution of the blast loading effectively acting on a structure vary greatly with

(a) Properties of explosive (type of material, quantity of explosive and energy output),

(b) Location of detonation relative to the structure, and

(c) Reflections of shock front on the ground and structure

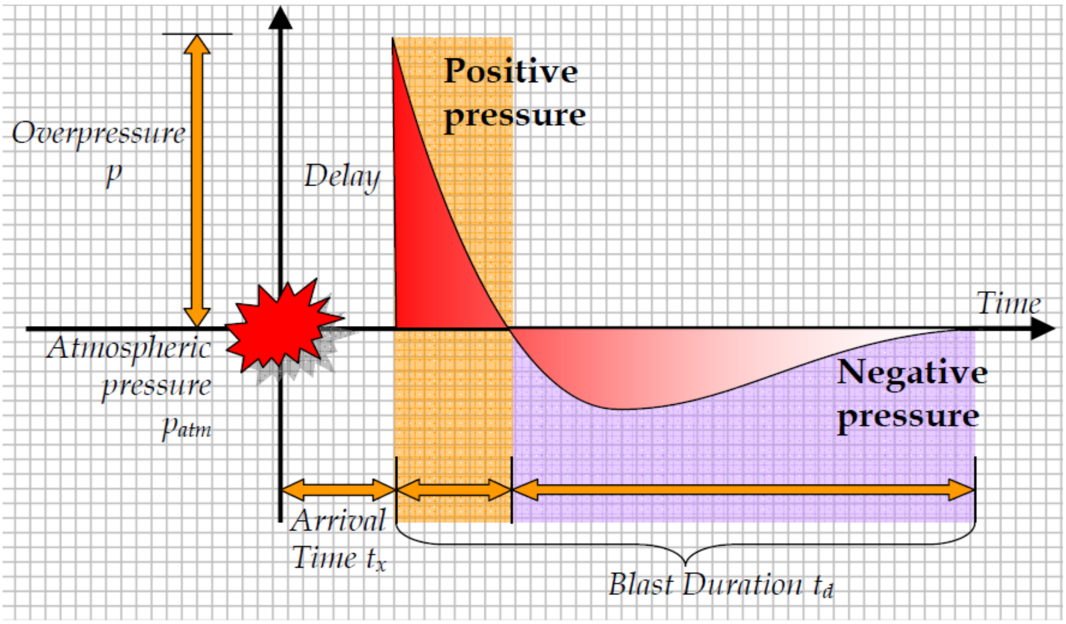

Fig. 1. Blast characteristics: Overpressure time history with critical blast parameters

A number of studies on the lateral load response of buildings have been carried out by researchers.

Mohammed Ettouney et al [7]. The paper addresses the design of floor slabs, columns, facades, atrium areas, windows and prevention of progressive collapse in the blast environment. The authors

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have presented design modifications that may limit the occupant's exposure to extreme blast pressures and have provided details that improve ductility and structural response characteristics. The authors have also provided certain provisions for the structure to improve blast protection capability of the building like using a well distributed lateral load resisting mechanism through several shear walls, strengthening the spandrel beams etc.

Mendis and Ngo [3]. The authors have analyzed a 52 storey tall building for ground blast at 20 m distance and impact loading of 320 kN using RUAUMOK program and the progressive collapse of structure is studied in LS DYNA. The research showed that the structural integrity of the example building depends greatly on the ability of structural members to deform in elastically under extreme loads, thereby dissipating large amounts of energy. By increasing the ductility of the floor slab connections the floor's ability to absorb energy will also increase. Member ductility is the key feature to prevent collapse of the structure.

II. METHODS AND MATERIALS

1. Objective: The purpose of this study is to analyse the relative performance of typical 45 storey reinforced concrete symmetric building for 500kg of TNT placed at different locations.

2. Description of the buildings used in the study: After a preliminary study on wall-frame buildings of different heights, a typical reinforced concrete office building of 45 storeys was selected for dynamic analysis, because it represents a typical high-rise building. For 45 storey building wind, rather than earthquake action, dominates the lateral loading. All 45 storey buildings had a storey height of 4.2 m. A constant building width of 42m and length of 45m is kept.

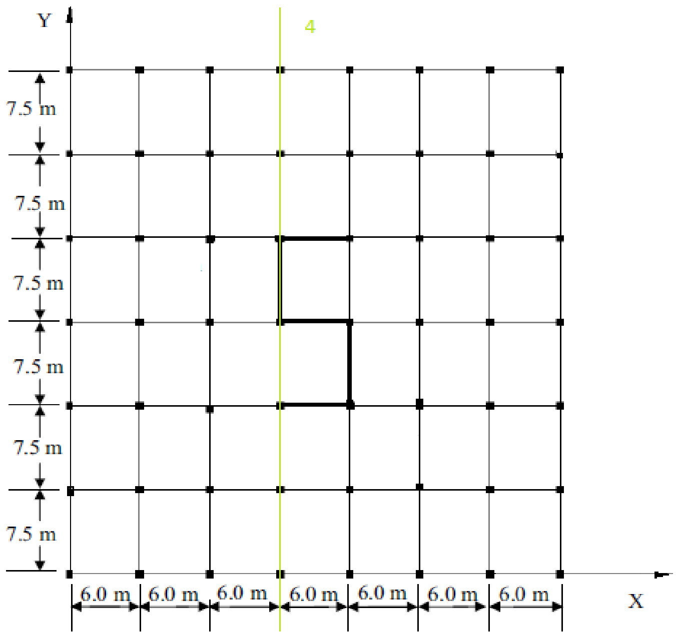

Fig. 2. Typical floor plan for the buildings (element sizes not to scale)

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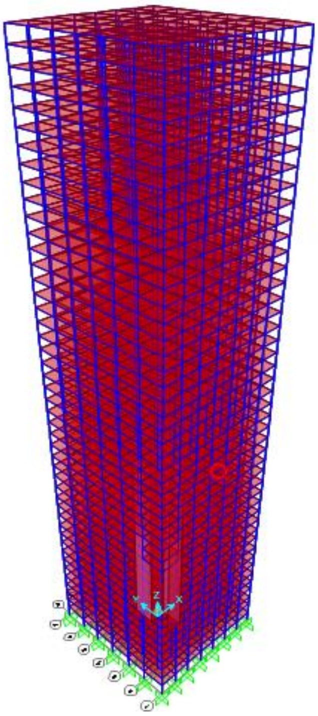

Fig. 3. 3D SAP 2000 model of 45 storey high rise R.C.C building

- Live Load: 4 kN/m2 at typical floor
- Story height: 4.2 m
- Floors: 45
- Size of Beams: 900 mm x 900 mm
- Size of Column: as per Static analysis (design)
- Thickness of floor slabs: 200 mm
- Thickness of Shear wall: 400 mm

3. Blast analysis: The two equally important parameters that directly influence the blast loading on a structure are the charge weight and the standoff distance. The charge weight can be expressed in terms of an equivalent mass of TNT. Ambrosini [10] suggest that 200-500 kg of TNT corresponds to the medium range of terrorist attacks to buildings. For most civilian buildings situated in urban settings large standoff distances are unattainable.

The 500-kg charge weight marks the upper boundary of TNT weight used in the medium range of terrorist attacks to buildings, the 30m, 40m and 50m standoff distance is chosen as per IS 4991-1968 that is practically possible in urban settings. In case of air blast, some stories are selected randomly as 8th, 23rd and 38th storey level. Using table 1 of IS 4991-1968 [11] the magnitude and the pressure time history of the blast load were calculated.

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The main assumption here was forces which are time varying and triangular those were acting on each beam-column joint on the front face of the building. The pulses decay linearly and have zero rise time as shown in Figure 8. The variation in the time of arrival of the blast waves at various points, depending on the distance to the joint, was also considered in constructing and applying loading functions.

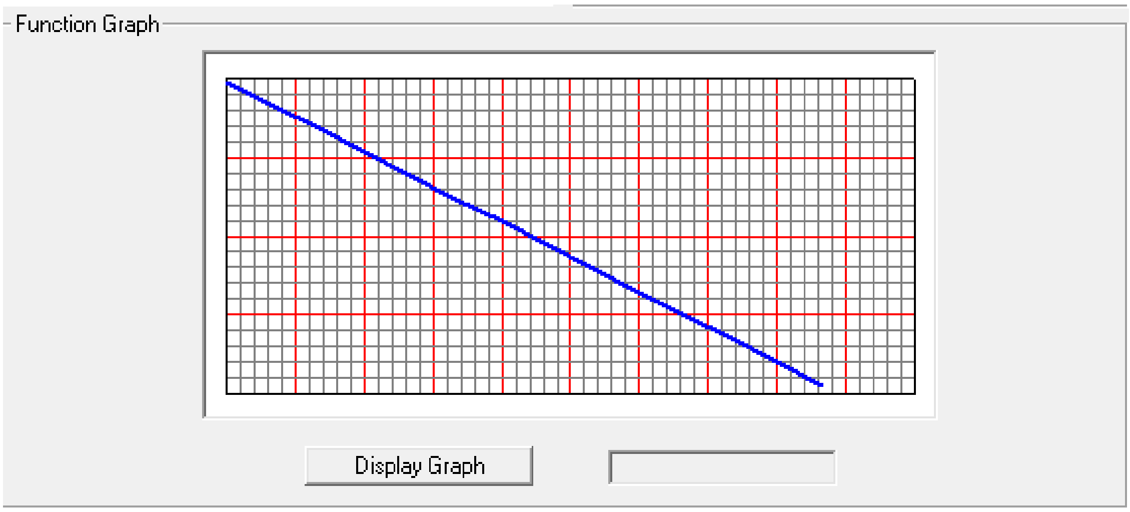

Fig. 4. Typical time history function generated by SAP 2000

III. RESULTS

Overall response results: The building response is characterized by that of the fourth in-plane frame from the left-hand side (see Figure 6), as this was found to have the maximum response. The top and maximum response values of all buildings obtained from the analyses are presented in Tables 1 with story at which it occurs. Immediately after the blast the maximum acceleration response occurs and maximum displacement occurs a stage later in time history.

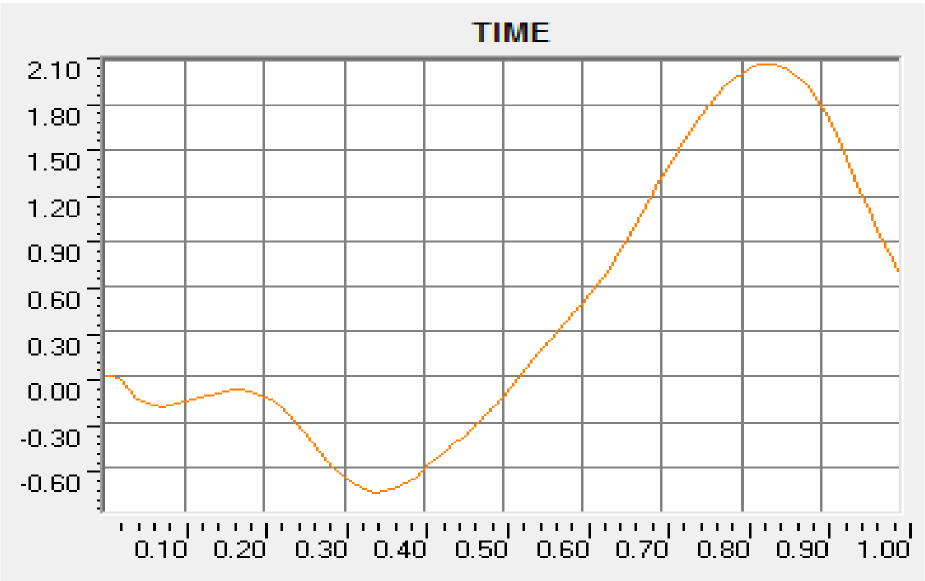

Fig. 5. Plot function for acceleration

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TABLE 1. Nonlinear Dynamic Response

Response Criteria	***Standoff Distance***		
	30m	***40m***	***50m***
Top Displacement (m)	0.372	0.274	0.168
Top Velocity (m/sec)	1.554	1.130	0.720
Top Acceleration (m/sec2)	8.881	6.750	4.442
Max Displacement (m)	0.525 (35th)	0.390 (35th)	0.205 (15th)
Max Velocity (m/sec)	3.500 (9th)	2.820 (9th)	2.120 (8th)
Max Acceleration (m/sec2)	210.05 (6th)	180.75 (6th)	132.12 (5th)

It has been observed that responses are maximum at lower storey because the effect of blast load is within lower storeys only. For variable blast source height responses are maximum at top stories because application of blast load is maximum at top for 23rd and 38th storey level blast. For 8th storey responses are maximum within lower stories.

TABLE 2. Nonlinear Dynamic Response

Response Criteria	***Blast source height***		
	8th storey	***23rd storey***	***38th storey***
Top Displacement (m)	0.794	3.356	2.273
Top Velocity (m/sec)	3.417	10.193	8.296
Top Acceleration (m/sec2)	10.714	98.670	278.21
Max Displacement (m)	0.979 (35th)	3.356 (45th)	2.273 (45th)
Max Velocity (m/sec)	4.420 (8th)	10.193 (45th)	8.296 (45th)
Max Acceleration (m/sec2)	238.32 (6th)	323.45 (37th)	287.96 (45th)

There are basically two types of failure i.e. Local and Global failure. Similarly, for high rise building these two failures are found out. Local failure is related with the number hinges developed in beams and columns i.e. whether that element fails or not? It can also be determined from Figure 6 by finding the members having red colored hinges. FEMA 356 is given a guide lines regarding the global failure which is based on the Inter Drift Ratio [22] which is calculated and performance level of building for each individual case is found out.

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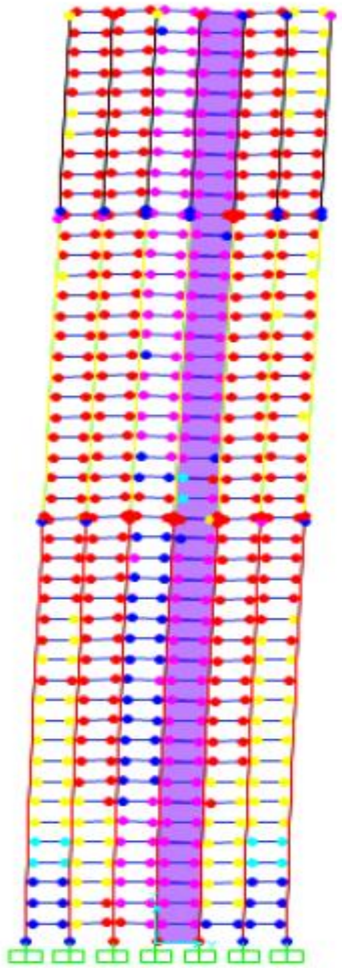

Fig. 6. Deformed shape of the building and development of plastic hinges in beam and cloumns

TABLE 3. Performance Level of Building

Case		***Max % IDR***	***Performance level***
Standoff distance	30m	2.57	Safe for CP
	40m	1.476	Safe for LS
	50m	1.143	Safe for LS
Blast height	8th	2.595	Safe for CP
	23rd	6.619	Unsafe for CP
	38th	5.238	Unsafe for CP

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IV. CONCLUSIONS

In present study, a 45 storey R.C.C symmetric high-rise building is analyzed for various blast loads. Based on the results of the analyses, the following major conclusions are made as follows:

- Variation of displacement is non-uniform trough the height of building and different from Earthquake and Wind (Building does not behave as cantilever structure under blast load).
- As standoff distance increases Non-linear dynamic response reduces.
- Performance level of building is reached to Collapse Point for minimum standoff distance.
- There is tremendous increase in response when blast occurs at mid height of building.
- Performance level of building is critical if blast occurs at upper half stories of building (building is totally collapse)
- Plastic hinges are developed in all beams for most of cases and in case of column hinges are forming at foundation and where column changes cross section.
- Performance level of plastic hinges connected to shear wall is below Immediate Occupancy, thus shear wall increases resistance of structural members subjected to blast.
- Thus, for the important structures, blast analysis needs to carry out by keeping in view the terrorist activities in today's scenario. Performance level of building and possible damages to the structure should also known for various locations of blast.

Conflict of interest: The authors declare that they have no conflict of interest.

Ethical statement: The authors declare that they have followed ethical responsibilities.

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