Analytical Study of Steel Column Failure Subjected to Blast Loading using Autodyn®

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ABSRACT: *Columns in a building are vital structural elements which resist lateral loads during earthquakes as well as should be robut enough to resist blast loads since failure of even a few columns may initiate progressive failure of a building. In the present paper, a column from a steel-moment-framed building is subjected to blast loading scenarios for blasts occurring outside the building and at ground level. The explosive material, trinitrotoluene (TNT) is placed at various locations with variable charge weight and standoff distance. The selected column is modeled in ANSYS Autodyn® maintaining its fixity and axial loads as in the main building. Response of the column is captured for different blast scenarios. The finding are helpful in predicting the progressive failure of the building.*

Keywords – *Blast Loading, Column failure, Peak reflected pressure, Progressive collapse, TNT.*

I. INTRODUCTION

The extreme loading conditions generated by blasts that result from terrorist attacks or accidental explosions can cause devastating consequences for structures and their occupants. Loss of life and injuries to occupants can result from many causes, including direct blast-effects, structural collapse, debris impact, fire, and smoke. In addition, major catastrophes resulting from gas-chemical explosions result in large dynamic loads, greater than the original design loads of many structures. Disasters such as the terrorist bombings of the U.S. embassies in Nairobi, Kenya and Dares Salaam, Tanzania in 1998, the Khobar Towers military attacks in Dhahran, Saudi Arabia in 1996, the Murrah Federal Building in Oklahoma City in 1995, and the World Trade Centre in New York in 1993 have demonstrated the need for a thorough examination of the behaviour of columns subjected to blast loads.

The column in a building is the most important element. The blast load induces lateral deformation in the column causing axial forces to form a couple which results in additional lateral deformation and bending in the column. Sometimes, one or more columns get damaged due to excessive deformation causing change in load distribution path in the structural elements above such as beams and slabs. This may result in progressive failure of the structure. In the present paper, a column from a steel-moment-framed building is subjected to blast loading scenarios for blasts occurring outside the building and at ground level. The spherical charge is placed at various locations with variable weight and standoff distances. The column is modeled in ANSYS Autodyn® maintaining its restraints and axial loads as in the main building. Response of the column is obtained for different blast scenarios.

II. BACKGROUND

In 1971, Dewey and Dewey [1] introduced the effect of spherical and hemispherical TNT 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. According to Dharaneepathy [2], a good prediction of the blast pressures is quite important blast-resistant design. The distance of blast location from the structure is an important parameter, governing the magnitude and duration of the blast loads. Ngo and Mendis [3] gave 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 helped creating design considerations against extreme events. Jinkoo et al. [4] in showed that beam yield strength was most important parameter in moment resisting frame buildings and column yield strength in dual system building. There is a need to study behaviour of columns when subjected to high velocity impacts or blast loads since their response affects a significant portion of the building.

III. METHODOLOGY ADOPTED

The three-storey steel moment frame office building considered herein consists of 4 bays @ 9.15 m and 2 bays @ 9.15 m in the two directions, respectively with storey height of 3.96 m (Fig. 1). Slab thickness is taken as 0.125 m. The building has been designed for gravity, wind, and seismic loads. The modelling of the building is done in ANSYS Workbench [5]. I–sections are used for beams and column cross-sections (American section W14x74). The front middle column at ground storey is isolated for the present study and modelled in ANSYS Autodyn. The blast simulation has been done using JWL equation of state for TNT in air medium. The column is subjected to four different scenarios of blast occurring at ground level—at standoff distances of 3 m and 5 m, each with TNT charge weights of 50 kg and 100 kg. The response of the column is captured at two gauge points: (i) at 0.5 m above ground support, and (ii) mid-height of the column, which are depicted in Fig. 2.

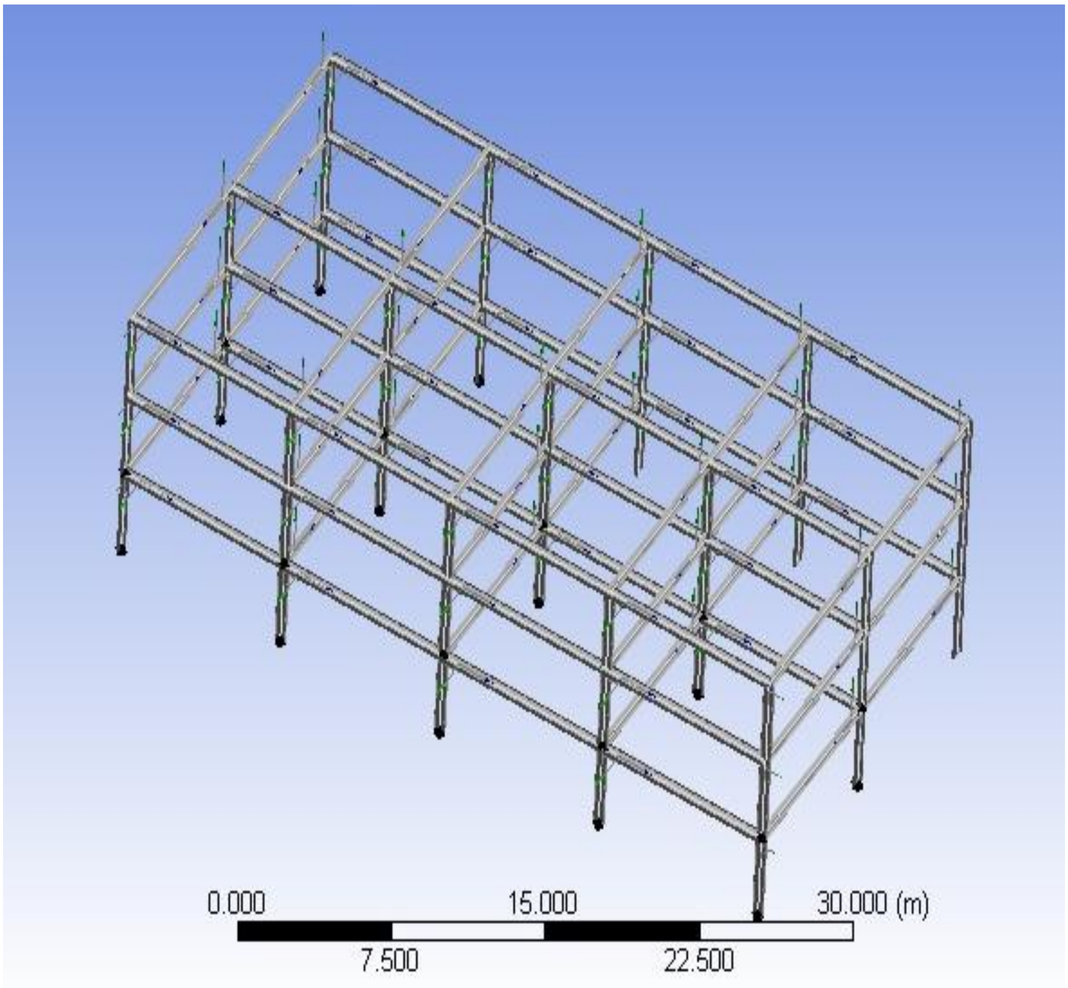

Figure 1: 3D View of Framed Building.

IV. RESULTS AND CONCLUSION

After the application of blast load, the pressure contours generated are shown in Fig. 3(a). The peak pressure vs time is also shown in Fig. 3(b) which shows that the pressure first increases rapidly and then decreases with the blast progression. Figures 4(a), (b) and (c) show pressure contours on and around the column, maximum principal strain, and stress variation in the column along with deformed shapes, respectively for illustration purpose after 1.47 milliseconds of the detonation for the first scenario.

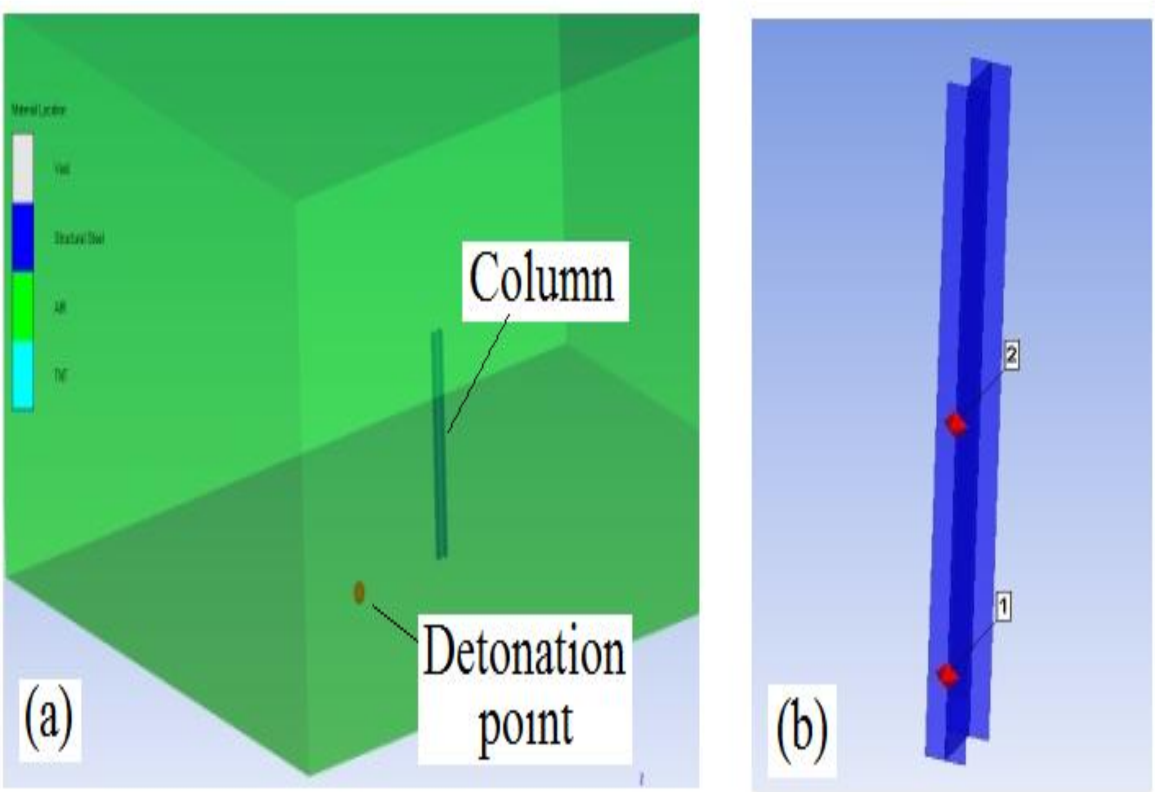

Fig. 2: (A) Column And Detonation Point, (B) Gauge Points For Response Computation.

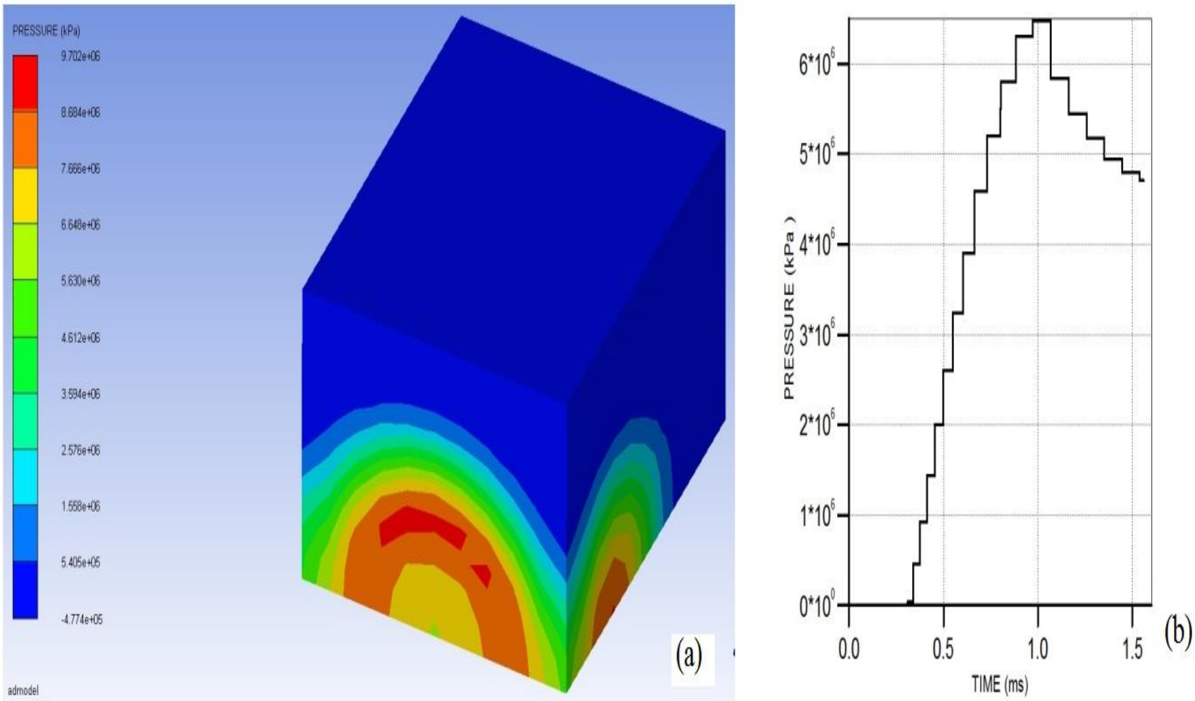

Figure 3: (A) Pressure Contours in Air Around Column, (B) Peak Pressure-Time History On Column.

The values of the various response parameters at gauge points 1 and 2 are given in Tables 1 to 4. The trends clearly indicate the importance of distance and charge weight on column's response.

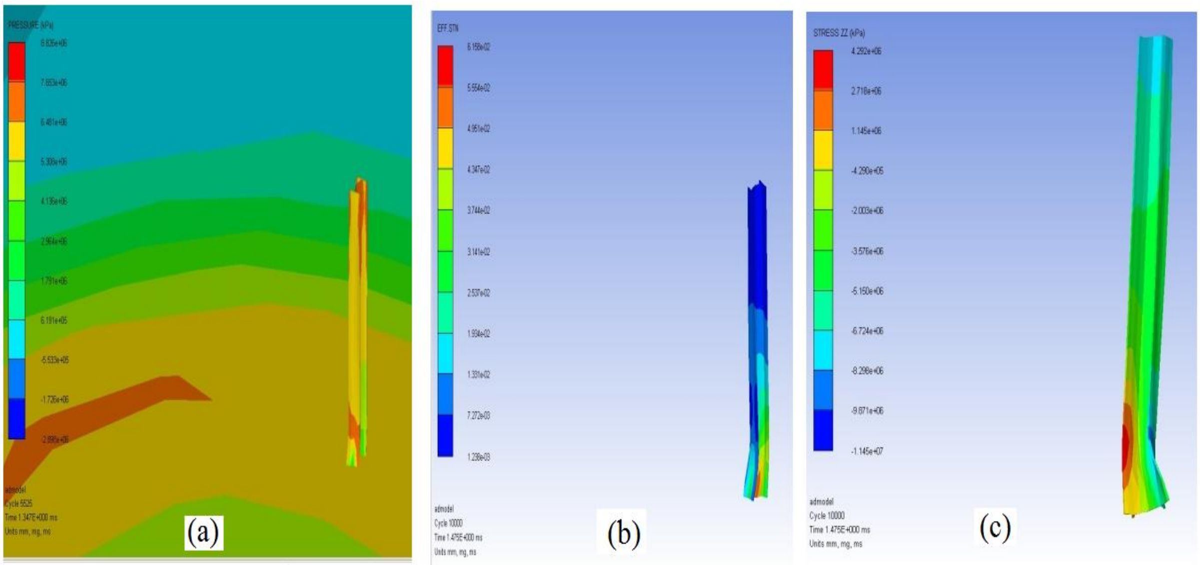

Figure 4: (A) Blast Pressure On Column, (B) Principal Strain Contours, And (C) Principal Stress Contours Due To Blast Load At 1.47 Ms.

Table 1: Maximum Blast Pressure (kPa) at Gauge points for different Standoff Distance and Charge Weight

	Gauge Point 1		Gauge point 2	
Weight of TNT	50 kg	100 kg	50 kg	100 kg
Standoff distance (m)				
3	6.78×10^6	8.98×10^6	4.94×10^6	5.96×10^6
5	4.63×10^6	6.79×10^6	4.5×10^6	4.33×10^6

Table 2: Maximum Stress (kPa) at Gauge points for different Standoff Distance and Charge Weight

	Gauge Point 1		Gauge point 2	
Weight of TNT	50 kg	100 kg	50 kg	100 kg
Standoff distance (m)				
3	-6.43×10^6	-4.71×10^6	-5.97×10^6	-4.97×10^6
5	-5.44×10^6	-1.73×10^6	-5.27×10^6	-4.71×10^6

Table 3: Maximum Displacement (mm) at Gauge points for different Standoff Distance and Charge Weight

	Gauge Point 1		Gauge point 2	
Weight of TNT	50 kg	100 kg	50 kg	100 kg
Standoff distance (m)				
3	3.46	4.53	1.14	2.54
5	2.52	3.51	0.8	1.89

Table 4: Maximum Strain at Gauge points for different Standoff Distance and Charge Weight

	Gauge Point 1		Gauge point 2	
Weight of TNT	50 kg	100 kg	50 kg	100 kg
Standoff distance (m)				
3	-2.64×10^{-2}	-9.04×10^{-2}	-1.84×10^{-2}	-4.53×10^{-1}
5	-1.893×10^{-2}	-1.32×10^{-2}	-1.34×10^{-2}	-1.32×10^{-2}

It is established that ANSYS Autodyn® is an efficient and user friendly tool for simulating explosives and impact loading linking it with workbench environment and the results are in correlation with the popular Kinney and Graham's approach for blast pressure computation. The blast simulation has carryout using JWL equation of state for explosive materials. From the present study, following conclusions are drawn.

1. Analytical study of column's behaviour clearly specifies that effect of explosion largely depends upon the standoff distance and charge weight.
2. For short standoff distances, the peak reflected pressure on column is significantly higher than for longer distance. The rise is pressure is of the order of 50% for part of the column near ground support.
3. Maximum principal stress and strain are seen to increase many fold for higher TNT charge weight placed at shorter standoff distance compared with smaller charge weight and larger standoff distance. This factor varies from two to as high as eight. This indicates that chances of column failure leading to progressive failure of the frame are higher.

The study presented provides some insight into behaviour of the column under blast loads and consequent possibility of progressive collapse of a building.

REFERENCES

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