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Modelling of Steel Column for Blast Load Effect's Investigation

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Abstract—*For the last two decades, the explosive devices are the weapons of choice for the terrorist attacks. The lesson learnt from the terrorist attacks is the need to assure structures their sustainability against the local damage and their behavior during a high strain rate loading. Several factors are responsible for the total collapse of a structure after the explosion. One of the most important factors is the catastrophic failure of column which leads to the failure of beam-slab system and thereby above causing progressive collapse of the entire structure. Thus the columns are needed to be investigated against such high strain rate to understand their behavior in such kind loading. Based on that, this paper represents a numerical model for analyzing a steel column to study its behavior under high impact loading in the form of energy caused by blast load. A column taken from a steel building is isolated and subjected to blat loading for different charge weights, and its collapse is observed. Modelling is done by using ANSYS Explicit dynamic and analysis of steel model against blast loading is done by using ANSYS AUTODYN. The column is seen to absorb significant amount of energy for lower charge weights while it collapses earlier for high charge weights.*

1. INTRODUCTION

The terrorist attacks and threats are the growing problem all over the world that not only affects the life of a human being but also the physical and structural integrity of the structures. If the structure is properly designed for these abnormal loads damages can be contained. An explosion is nothing but a sudden release of energy on a large amount which generates pressure waves of higher amplitude. These energy moves forward and forms a shock wave move supersonically i.e. speed more than the speed of sound in air ahead of it with discontinuity in particle velocity, pressure and density across these fronts. The movement of blast wave in air is a non-linear process and involving non- linear motion equations.

Explosive material can be classified according to their physical state such as solid, liquid or gaseous. Solid explosives are mainly high explosives for which the blast effects are well known. Classification is also done on the basis of their sensitivity to ignition as secondary or primary explosive. Some of the common examples of primary explosives are such as Mercury fulminate and lead azide and of secondary explosives such as trinitrotoluene (TNT) and ANFO. Explosives are widely used for demolition purpose in: Military applications or in construction and development process. But now these are also a very common terrorist weapon as it is available, easy to produce, compact and cause structural damage and injuries.

2. PHENOMENA OF EXPLOSION

The explosion of an explosive generates hot gases under pressure up to 300 kilo bar and a temperature about 3000-4000C^o . A layer of compressed air is formed due to expansion of these hot gaseous forcing out the volume it occupies and contains most of the energy released by the explosion. The pressure value increases above the ambient atmospheric pressure. After a certain short period of time, the pressure behind the front may drops below the ambient pressure (Fig. 1). This is known to be a negative phase, here a partial vacuum is created and air is sucked in. This is also accompanied by high suction high suction winds that carry the debris from long distance away from the explosion source.

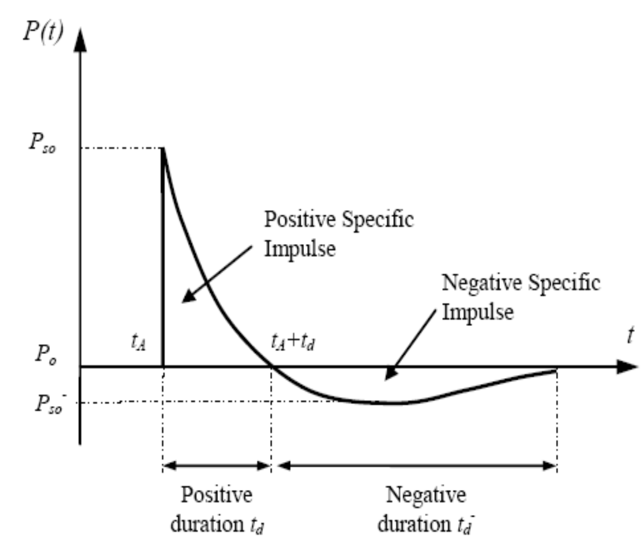

Fig. 1: Blast Wave pressure- Time History

TNT i.e. trinitrotoluene is considered as a reference for determining the scaled distance Z, and it is universal. The first step in quantifying the explosive wave from source other than TNT, is to convert the charge mass into an equivalent mass of TNT. Specific energy of different explosive and their conversion factors to that of TNT are given in Tab. 1.

Table 1

Explosive	Specific energy (kJ/kg)	TNT Equivalent
Compound B	5190	1,148
RDX	5360	1,185
TNT	4520	1,000
Nitroglycerin	6700	1,481
Semtex	5660	1,250

3. LITERATURE REVIEWS

"Blast Loading And Blast Effects On Structures–An over view" T. Ngo, P. Mendis, A. Gupta & J. Ramsa: This paper presents a comprehensive overview of the effect of explosion on structures. An explanation of explosion and the mechanism of blast waves in free air is given.

"Architectural and Structural Design For Blast Resistant Building" Zeynep Koccaz, Faith Sutcu, Needet Torunbalci: In this paper firstly, explosive and explosion type have been explained briefly. In addition, the general aspects of explosion process have been presented to clarify the effects of explosive on buildings and also shed light on blast resistant building design theories.

"A Review of Methods for Predicting Bomb Blast effects on Buildings" A.M. Remennikov: This paper presents some of the currently available analytical and numerical techniques that can be employed to effectively predict loads on structures when a terrorist weapon is detonated in urban environment.

"Blast Loading On Structures" Harvoje Draganic, Vladimir Sigmund: This paper Describes the process of determining the blast load on structures and provides a numerical example of a fictive structure exposed to this load. The blast load was analytically determined as a pressure-time history and a numerical model of the structure was created in SAP2000**.**

"An Abridged Review of Blast Wave Parameter" Manmohan Das Goel, Vasant A.Matsagar, Anil K. Gupta, Steffen Marburg: This paper is providing various blast computation equations, charts, and references in a concise form at a single place and to serve as a base for researchers and designers to understand, compare, and then compute the blast wave parameters**.** Recommendations are presented to choose the best suitable technique from the available methods to compute the pressure-time function for obtaining structural response.

4. EFFECT OF STRAIN RATE DUE BLAST LOAD

Strain rate affect the mechanical properties of steel on a large scale. If mechanical properties under static loading are considered as a basis, the increasing strain rate effect on steel is illustrated in Fig. 5. The yield strength of steel increases up to dynamic yield strength substantially. According to experimental evidences, it is observed that when the strain rate is very high the dynamic yield strength may increase beyond that the ultimate strength. The modulus of elasticity remains insensitive or unchanged to the loading rate. The ultimate tensile strength increases slightly but the percentage increase is less than that of yield strength. The elongation at rapture either reduced slightly due to increase strain rate or it either remains unchanged. The cross section classification is also affected by high strain rate due to increase in yield strength.

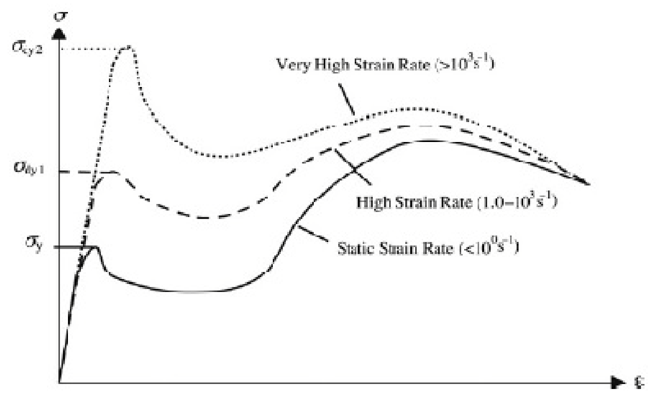

Fig. 2: Stress-Strain Relationship of steel under High strain rate

5. STRUCTURAL RESPONSE TO BLAST LOADING

Analysis of structure under blast loading varies from single degree of freedom system (SDOF) or Multi degree of freedom system (MDOF). The SDOF system is applied on a single element that involves simplification of continuous structural member into a dynamic system with equivalent mass and stiffness. The MDOF system represents the response of multi storey frame where the floors are represented by their concentrated masses. The classical dynamic solution methods or design charts can be used to find the solutions of SDOF/MDOF system. In order to establish the principal of analysis, the response of SDOF elastic structure is considered and the link between the natural time period and duration of blast load on structure established. Finite element model method is also an effective method for the analysis of structure response in dynamic condition. This method is based on beam element model by considering the interaction effect between the individual member and overall framework. This could be understood from the example i.e. the redistribution of forces cause the buckling and yielding of one or more members and weakens the structure to resist the further loads. The finite element formulation also includes the material and geometrical non-linearity.

6. FINITE ELEMENT ANALYSIS

The effect of an explosion of spherical charge of TNT of various masses (20kg, 50kg, 100kg) are considered for the analysis of steel column of a multi storey building which was modelled using SAP 2000 v16. The example or a model was taken from Stefan Szyniszewski (2012); Ted Krauthammer "Energy flow in progressive collapse of steel framed buildings". The structure was modelled with beam element for girders and columns and shell elements for slab. Framing plan of modelled is shown in Fig. 3

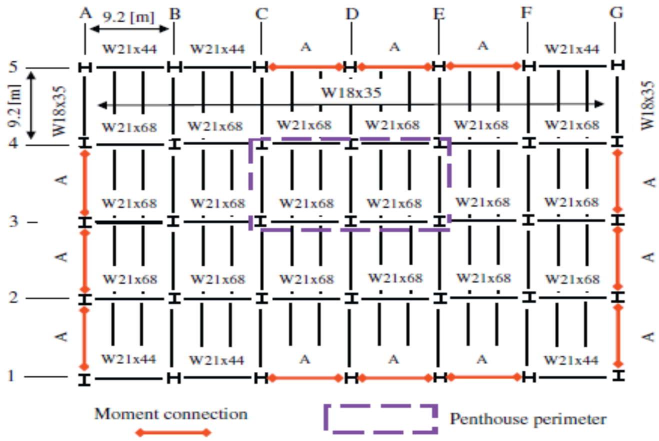

Fig. 3: Framing plan of Steel structure [1]

A steel column is taken from the above structure for the blast analysis which is much nearer to the explosive source i.e. at stand-off distance R = 1m with angel of incidence of 45 degree. The 1 kg of TNT produce 4184 kJ of energy based on that energy produced by 20 Kg , 50 Kg and 100 Kg was calculated and applied in analyses of steel column on ANSYS Autodyn-3D. The modelling of column is done in ANSYS Explicit Dynamic and properties of steel is as shown in table 2

Table 2: Steel column properties

Area of cross section (m2)	16.7
Overall Depth (mm)	535
Width of flange (mm)	166
Thickness of flange (mm)	16.5
Thickness of web (mm)	10.5
Moment of Inertia about string axis (mm4)	486990767
Length of steel column (m)	5.0
Mass Density (kg/m3)	7830

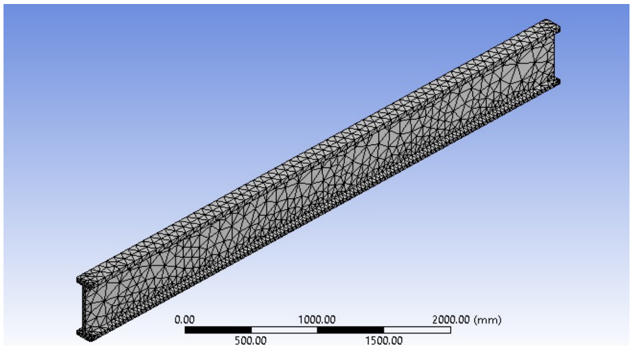

Fig. 4: Geometry of steel column With CFX mashing

The model is analysed in AUTODYN-3D and it is surrounded by air having ambient pressure of about 101.30 kPa. The analysis is done by using three material defined in ANSYS AUTODYN i.e. Steel, Air and TNT. Air is modelled as 2D Multi-fill material part.TNT filled using geometric shape and location of explosive is defined The AUTODYN environment and workspace with defined parts is as shown in Fig. 5.

Table 3

PARTS	DENSITY (g/cm3)	INT. ENERGY (J)
Air	0.00125	2.060e+005
TNT (1kg)	1.630	4.184e+006
TNT (20kg)	1.630	83.68e+006
TNT (50 kg)	1.630	209.2e+006
TNT(100 kg)	1.630	418.4e+006

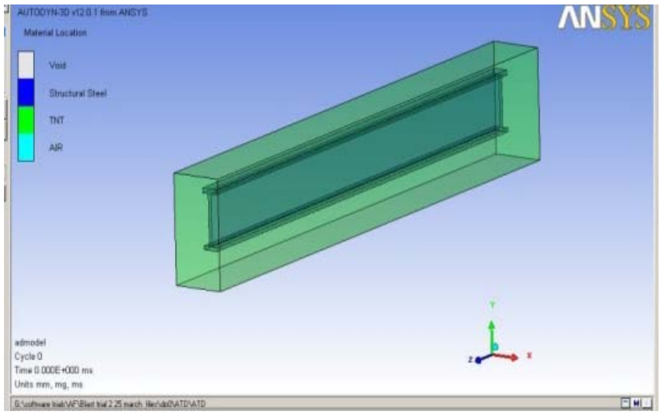

Fig. 5: AUTODYN Environment

The density and internal energy of air and TNT which is used during the analysis is shown in Table 3

7. RESULTS

The energy produced due to 20 kg TNT is about 83680 kJ causing total collapse of steel column after 1204 cycles at 0.426 ms (as shown in Fig. 6). The pressure contour and Material summery are shown in Fig. 7.

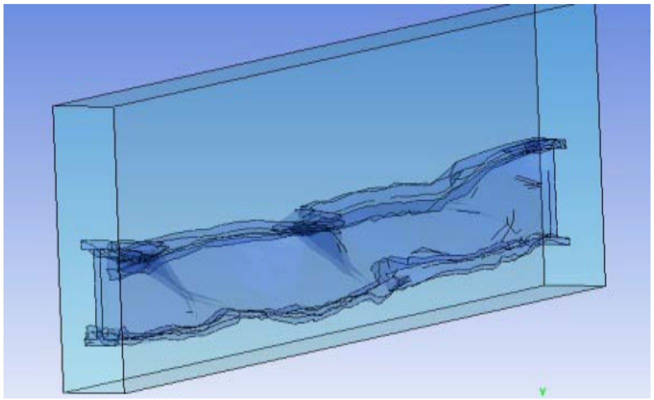

Fig. 6: Total Collapse of Steel Due after 1204 cycle

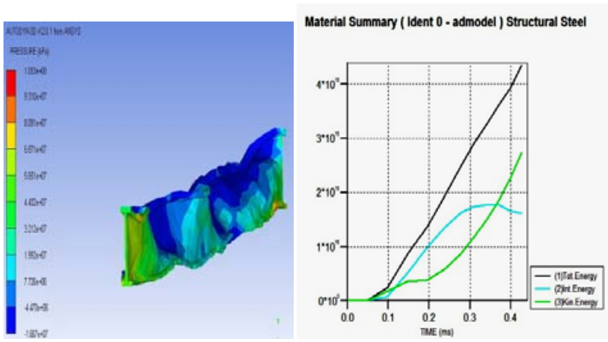

Fig. 7: a) Pressure contour b) Material summery

TABLE 4:- MAX/MIN value of Energy

Minimum		Maximum	
X	Y	X	Y
0	1.000e-010	4.2639e-001	4.3467e+015
0	1.000e-010	3.1480e-001	1.7734e+015
0	1.000e-010	4.2639e-001	2.7265e+015

Similarly, the analysis of steel is done by applying energy produced due to 50 kg and 100 kg TNT as shown in Fig.

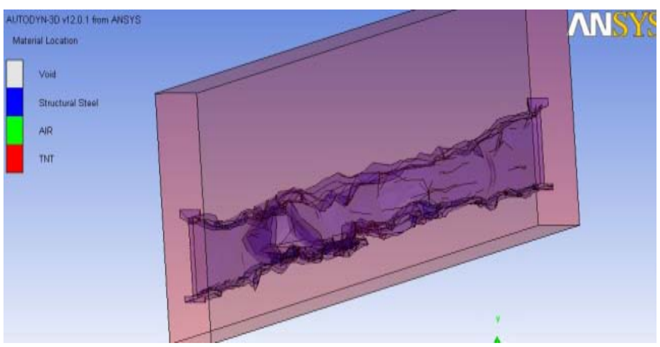

Fig. 8: Total collapse after 950 cycles

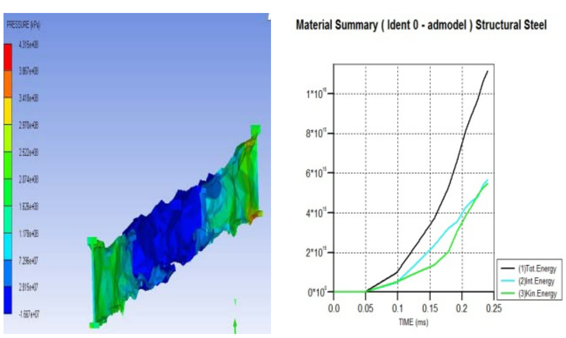

Fig. 9: a) Pressure contour b) Material summery (50 kg)

Table 5: MAX/MIN value of Energy (50 kg)

Minimum		Maximum	
X	Y	X	Y
0	1.000e-010	2.4051e-001	1.1132e+016
0	1.000e-010	3.1480e-001	5.6654e+015
0	1.000e-010	2.4051e-001	5.4669e+015

Effect Due to 100 Kg TNT

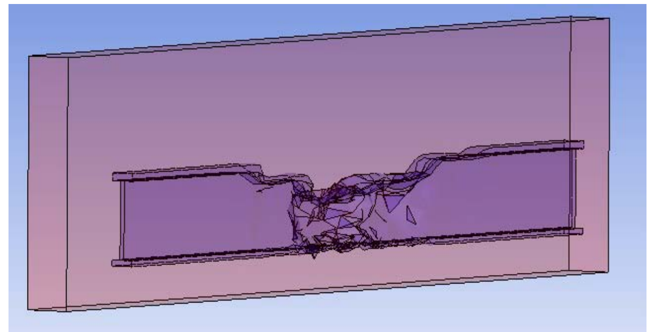

Fig. 10: Total collapse after 587 cycles

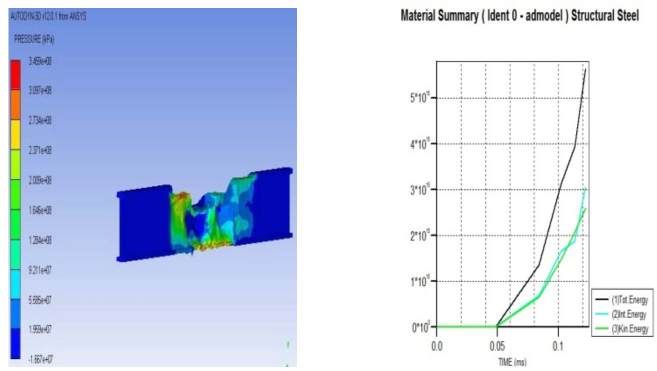

Fig. 11: a) Pressure contour b) Material summery

Table 6: MAX/MIN value of Energy (100 kg)

Minimum		Maximum	
X	Y	X	Y
0	1.000e-010	1.2252e-001	5.6111e+015
0	1.000e-010	1.2252e-001	3.0369e+015
0	1.000e-010	1.2252e-001	2.5842e+015

8. CONCLUSIONS

From the studied carried out above, the following conclusions are drawn:

1. For higher charge weights, the collapse occurs faster, as is evident from the graphs. The column fails in half the time for 50 kg TNT than for 20 kg TNT, whereas for 100 kg TNT, it takes about one-fourth the time to fail than 20 kg TNT.
2. In case of 20 kg TNT blast, the internal energy of the steel column reduces after about 0.35 ms of loading, while no reduction in this energy is seen for charge weights beyond this. This occurs prior to failure starts.
3. For 20 kg and 50 kg charge weights, the internal energy remains beyond kinetic energy until failure starts, while for 100 kg charge weights, both the energies remain approximately the same. This may be attributed to the very high impulse pressure of shock waves for higher TNT weights.

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