Numerical Analysis of Steel Building Under blast Loading

Mohammad M. Abdallah[1],
[1]College of Civil and Transportation Engineering,Hohai Univ.,
No. 1 Xikang Rd., Nanjing City,
Jiangsu Province210098, China.

Bashir H. Osman[2,3]
[2]College of Civil and Transportation Engineering,Hohai Univ.,
No. 1 Xikang Rd., Nanjing City,
Jiangsu Province210098, China.
,[3]Sinnar University, Engineering Collage,
Civil Eng. Department–Sinnar - Sudan

Abstract:- **Explosions are widely used for demolition purpose such as in construction or development works, military applications and destruction. But also it is common to use in terrorist activities and easy to produce with a great power to cause structural damage and injuries.The aim of the paper is to understand the explosion phenomena and its load on structures by introducinga historical studies and equations.Moreover, finite element program SAP2000 was conducted to study and analyze the real behavior of steel structure which subjected to blast loads withdifferent charge weights at the same building situation.The main parameters considered in this study were displacement, terrorist threat and demand capacity ratio (D/C). The blast load was determined as a pressure-time history.**

Keywords:Blast Load, Pressure-time history, SAP2000, Displacement, D/C. ratio.

1. INTRODUCTION:

Before 1960's the dealing with blast loadanalysis and design was confined for facilities where accidental or chemical explosions could happen, but today there has been increased awareness about safety of public buildings from intentional/unintentional blast load since of the growing of number and intensity of domestic regions which suffer from terrorist activities. The September 11, 2001 attack on World Trade Center towers in New York is one of the most world actions which led researchers to increase attention and studies on the effects and resistivity to blast load.Because of that, effects of blast loading on the structures, structural engineers have developed methods for structural design and analysis against blast loads, also engineers in the military developed empirical methods to predict blast loads parameters, Army TM5-855-1 and Army TM5-1300.

The analysis and design of the structures for blast load requires understanding the explosion phenomena and the dynamic response of the structure. Blasting load can be defined as the load result from the explosions or chemical ammunitions. The threat of bomb depend on two factors, which shows in Fig1, the bomb size or the charge weight (W), and the standoff distance between the blast source and target(R).

The main results of detonation are the temperature, which depend on the weight of charge and material properties, and the hot gases which expand out of the occupied volume forming an air waves (blast waves) at the front, which contain the most of energy released by explosion.

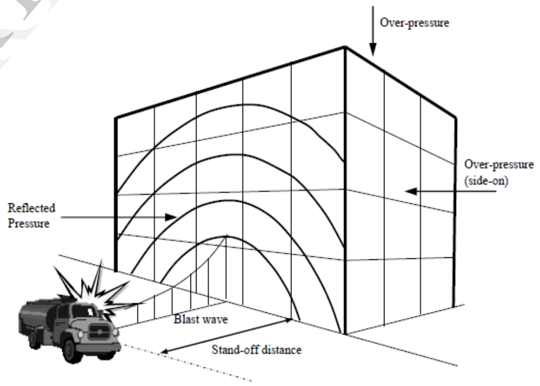

Fig.1. Blast load on building.

The main objective of this study is to understand the explosion phenomena numerically and its load on structures by introduces a historical studies and equations, also to study the behavior of 3D steel structure under blast load.

2. RESEARCH PROBLEM

Explosions is widely using for demolition purpose in construction or development works, military applications, demolitions, etc. but also it is common to use in terrorist activities, and easy to cause structural damage and injuries. The analysis and design of structures against the stresses induced by explosion still rather limited.

The blast wave usually affected by the physical properties of the explosion resource, so the strength of the wave normally depending on the distance and the weight of charge.

3. MATERIALS AND METHOD

In order to validate the model and the solution of present study, a three-dimensionalnonlinear finite element analysis was conducted to study the general behavior of steel building under blast load and detailed in Table 2.
The estimated quantities of explosion in various vehicles, charges weight and exposure side used according to Table 1.

Table 1. Estimated quantities of explosions in various vehicles [1]

Vehicle type	Charge mass / kg
Compact car trunk	115
Trunk of a large car	230
Closed van	680
Closed truck	2 270
Truck with a trailer	13 610
Truck with two trailers	27 220

Table 2. Model description

Number of X bays	6
Number of Y bays	4
Number of stories	4
The span length in X direction	6
The span length in Y direction	4
The story height	3

*Note: all dimensions in meter.
The models conducted for this study involve three different charges weights varied from 10 – 100Kg. the building was analyzed and designed according to BS 5950-1-2000 code before subjected to blast load. There are two different joints connections were considered, the first one is pin connection and the second one is moment connection as in Fig.3.

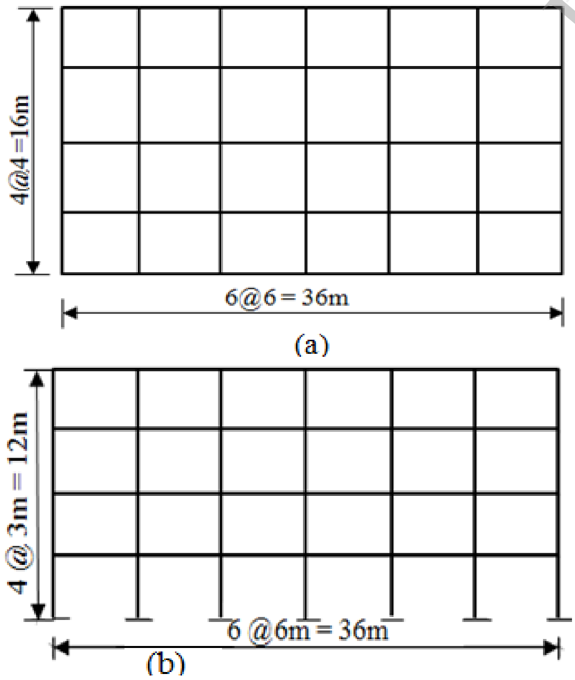

Fig.2. building arrangement (a) plan (b) elevation

The parameters used for analysis and designs are moment resisting frames, outer joints assumed as a moment connections, inside connections assumed as pinned connections, combined dead and live loads are assumed [1.4(DL+ Imposed DL)+1.6LL], buildings using for office and composite slab with total thickness 14 cm.

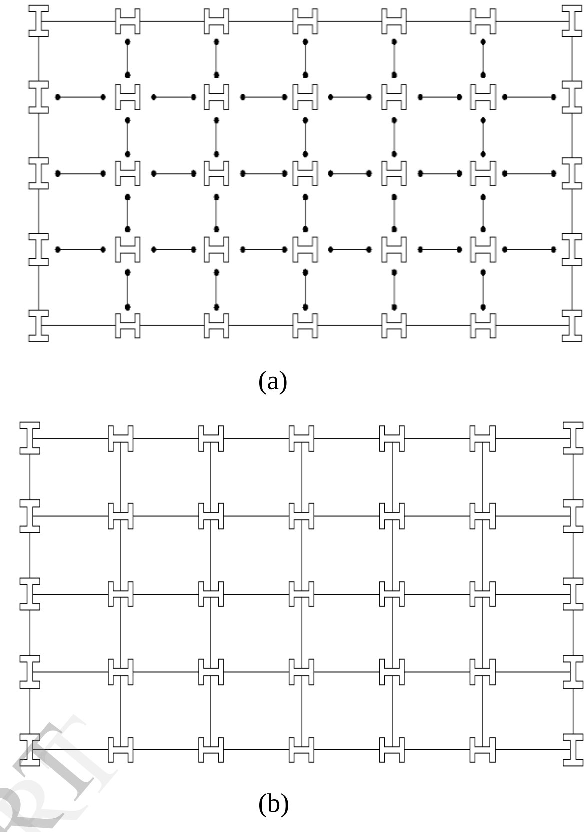

Fig.3. Connection type (a) pin connections joints (b) moment connection joints.

3.1. 3D finite element modeling:

To obtain the response of the model for different charge weights at the same stand-off distance, SAP2000 software was used to analysis the model based on design parameter and load time history of each member. The dynamic time history indicates that number of output time steps is 1000 and output time step size is 0.005, also the damping ratio was assumed as 0.05.Time history profile is a model to express the explosion phenomena based on the pressure released from the explosion resource versus different time stages as shown in Fig.4.

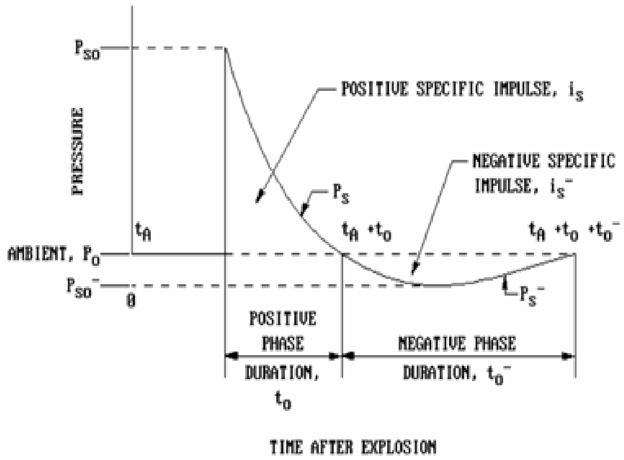

Fig.4.Exponential Decay of Pressure-Time History [3]

Exponential functions as Friedlander's equation [4] consider the basic unit which modeled the blast wave time history which illustrated in Equation 1.

$$P_s(t) = P_{s0}(1-\frac{t}{t_0})e^{-b\frac{t}{t_0}} \quad (1)$$

Where: P_{so} is the peak overpressure, t_0 is the positive phase duration, b is a decay coefficient of the waveform and t is the time elapsed, measured from the instant of blast arrival.

3.2. Scaling laws

Blast wave scaling law is the distance of the detonation point from the structure of interest (Hopkinson-Cranz (1915)). It is consider one of the most critical parameters for blast loading computations, because of the peak pressure and wave velocity decrease by the distance from the explosion resource. The scaling law expressed in equation 2.

$$Z = \frac{R}{W^{1/3}} \quad (2)$$

Where:Z is scaled distance, R is the distance from the detonation source to the point of interest [m] and,W is the weight of the explosive (charge, TNT) (kg)

3.3. Incident and Reflected pressure

Because of the energy release from the detonation, the pressure increase from the ambient pressure to incident pressure (P_s), and the incident pressure is the pressure on surface parallel to the blast wave direction. But if the blast wave encounters an obstacle perpendicular to the direction of wave direction, the reflection changes the pressure to the reflected pressure. The incident pressure was presentedin equations (3 – 6) by Brode,Newmark and Hansen, and Mills, respectively.

Brode [5] separated it into two levels (near and medium to far away):

$$P_S = \frac{6.7}{Z^3} + 1bar \quad (3)$$

For Ps > 10 bar

$$P_S = \frac{0.975}{Z} + \frac{1.455}{Z^2} + \frac{5.85}{Z^3} - 0.019bar \quad (4)$$

For 0.1 bar<Ps<10bar

Newmark and Hansen [6] at 1961,

$$P_S = 6784\frac{W}{R^3} + 93\left(\frac{W}{R^3}\right)^{1/2} \quad (5)$$

And Mills [7] at 1987,

$$P_S = \frac{1772}{Z^3} - \frac{114}{Z^2} + \frac{108}{Z} \quad (6)$$

The equation for reflected overpressure in terms of ambient and incident pressures estimated by Rankine and Hugoniot as in equation 7.

$$P_r = 2P_s\left[\frac{7p_0 + 4p_s}{7p_0 + p_s}\right] \quad (7)$$

Where: P_r is reflected pressure, p_s is incident pressure, and p_0 is the ambient of air pressure.

3.4. Dynamic pressure and blast wave velocity

Dynamic pressure or drag pressure is that pressure which produced on the structural surface from the air behind the front of the blast wave which moves in the same direction as a wind but with smaller velocity. The initial value of dynamic pressure (q_0) is less than that of the incident or reflected pressures for medium and small overpressure values, also it is need a period longer than the period of the incident or reflected pressures. The velocity of blast wave and dynamic pressure equations in terms of incident pressureintroduced in equation 8 based on Rankin (1870) expression.

$$U_s = \sqrt{\frac{6p_s + 7p_0}{7p_0}}.a_0 \quad (8)$$

$$q_s = \frac{5p_s^2}{2(p_s + 7p_0)} \quad (9)$$

Where: U_s is the velocity of wavefront, P_S is the overpressure, P_0 is the ambient of air pressure, a_0 is the speed of sound in air and q_s is the dynamic pressure.

3.5. Joints constraint type

The model distributed into two cases based on the joint constraints type, the first case was to consider all the internal joints as pin connections, moment released, and only the parameter frames joints were as a moment connections, and in case two all the joints considered as moment connection joints as in Fig 3.

4. RESULTS AND DISCUSSIONS

The model subjected to three different charges weights of 10, 50 and 100kg at the same stand-off distance of 4.5m which illustrated in fig5. The method which used for determine blast loads was by selected several points at the model front façade to calculate the peak reflected pressure values at each one.Load distributed on the model frames based on the tributary area and the average value of each frame member points. The analyses is summarized in two cases, case one defined as pin joint connection either case two is moment joint connection.

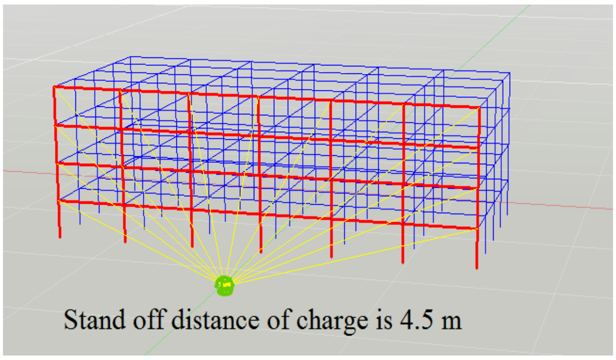

Fig.5.The model front façade with stand-offdistance of charge source

4.1. Effect of charges on displacement

The results and building response to explosion based on joints connection were illustrated in Fig(6-8) with different charges weight. Moreover, the behavior of each story with the maximum displacement and demand capacity ratio

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 3 Issue 11, November-2014

(D/C) was conducted.

For pin connections (case one), Fig (6-8) shows the displacement increased with increase in building height in all TNT values and vice versa**.** The maximum displacement of each floor plotted in Table 3.

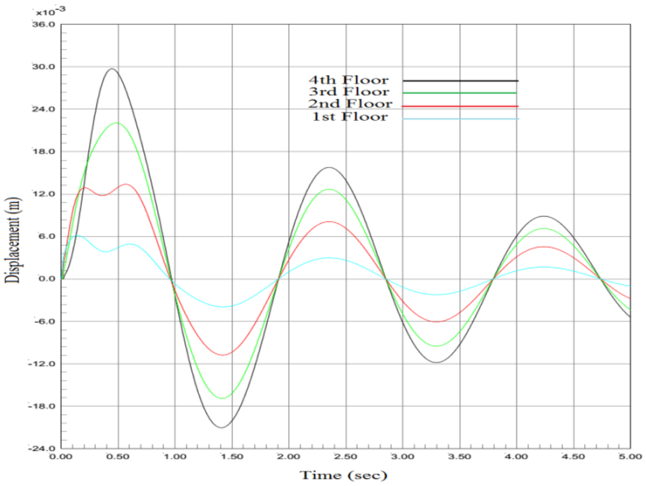

Fig.6. 10 kg TNT at 4.5 m stand-off distance

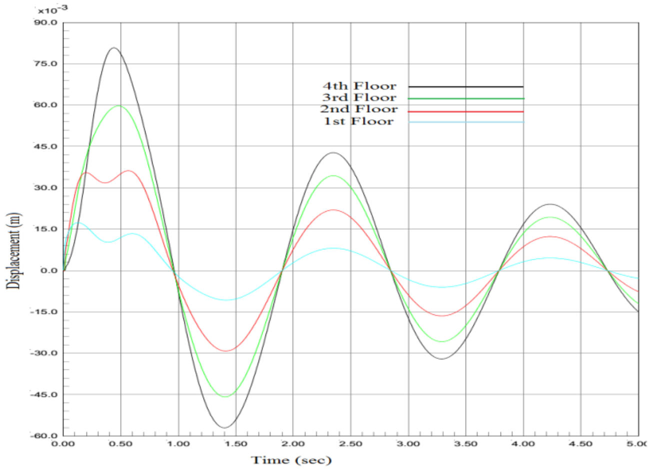

Fig.7.50 kg TNT at 4.5 m stand-off distance

Table.3. Time - Maximum displacement of case one floors

	10Kg TNT		50Kg TNT		100Kg TNT	
Floor no.	Max displacement(mm)	Time (sec)	Max displacement(mm)	Time (sec)	Max displacement(mm)	Time (sec)
1	6.13	0.145	17.36	0.13	27.82	0.12
2	13.37	0.570	36.20	0.565	57.17	0.565
3	22.05	0.485	59.73	0.48	94.32	0.48
4	29.71	0.445	80.82	0.44	127.7	0.44

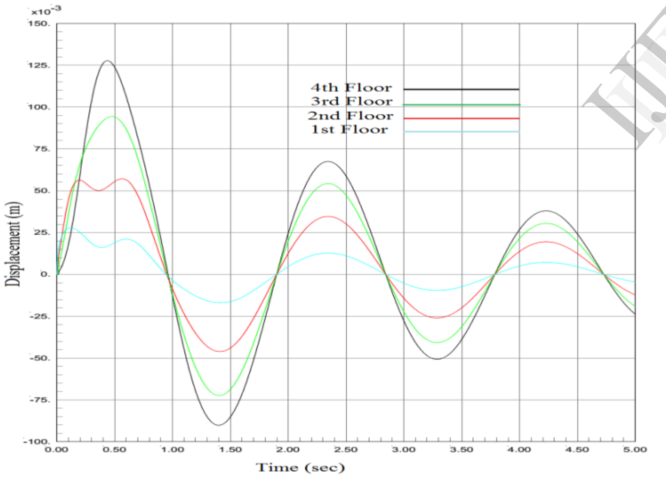

Fig.8. 100 kg TNT at 4.5 m stand-off distance

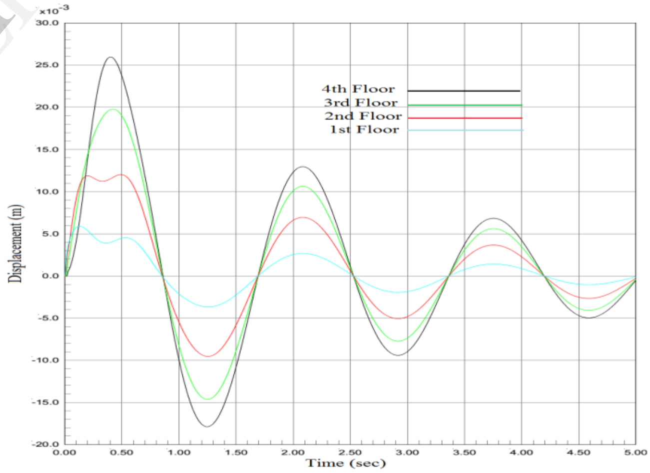

Fig.9.10 kg TNT at 4.5 m stand-off distance

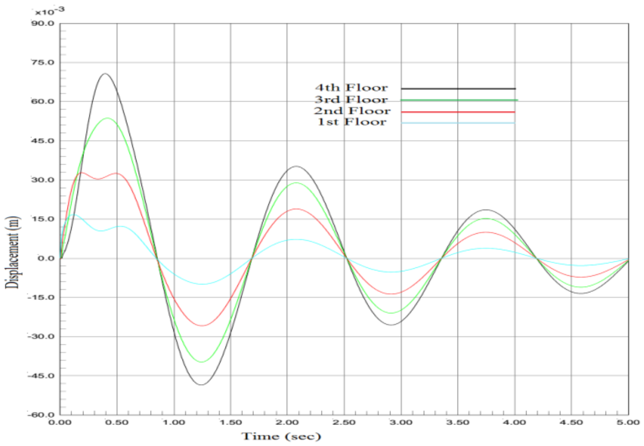

Fig.10. 50 kg TNT at 4.5 m stand-off distance

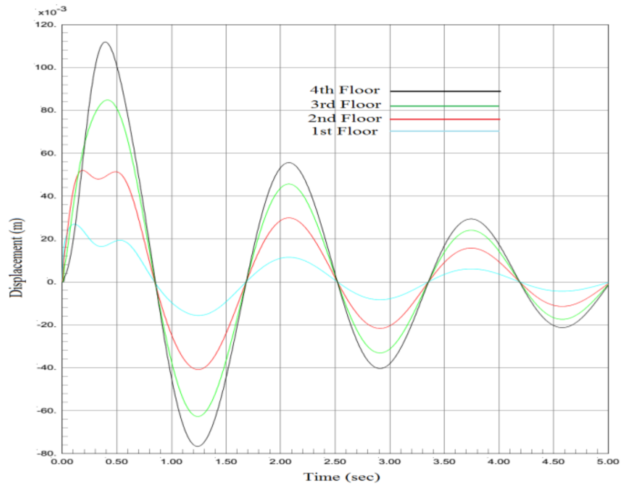

Fig.11.100 kg TNT at 4.5 m stand-off distance

For moment connections (case two):Fig (9-11) shows the displacement increase with increase in building height in all TNT values and vice versa. The maximum displacement of each floor plotted in Table 4.

Table.4.Time - Maximum displacement of case two floors

10Kg TNT			50Kg TNT		100Kg TNT	
Floor no.	Max displacement(mm)	Time (sec)	Max displacement(mm)	Time (sec)	Max displacement(mm)	Time (sec)
1	5.89	0.13	16.74	0.115	26.89	0.11
2	12.02	0.49	32.78	0.19	52.01	0.185
3	19.78	0.42	53.66	0.415	84.77	0.415
4	25.97	0.40	70.72	0.395	111.8	0.395

Fig 12, 13 and 14 show the results of D/C in the columns of exposure side. The values of D/C were increase with the building height decreasing up to third floor, after that the value of D/C lead to decrease with building height decreasing as in Fig 13 and Fig 14.

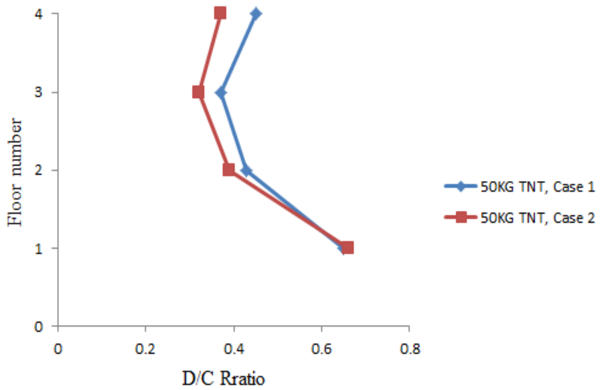

Fig.13.Columns D/C ratio of two cases with 50 kg TNT

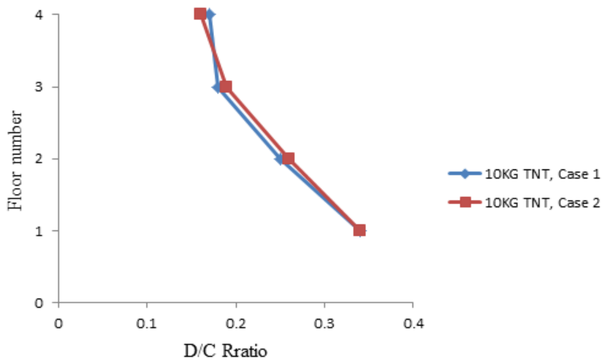

Fig.12.Columns D/C ratio of two cases with 10 kg TNT

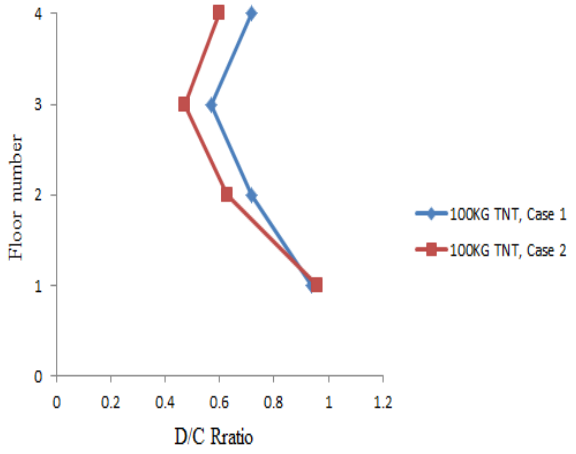

Fig.14. Columns D/C ratio of two cases with 100 kg TNT

5. CONCLUSION:

The explosion near to structure can cause hazard damage on the building, analysis and design the building to resist blast load should take into account recently, due to the growing in terrorist attacks, so the effect of surface burst explosion introduced by studying 3D steel structure behavior under three different weight charges at the same stand-off distance. A several points were selected at the model front façade to calculate the reflected pressure and the duration time, and then the pressure-time history functions defined for each member by using SAP2000 software. Based on the maximum displacement figures the case two was a bit better than the first case to resist blast load due to the moment connections,the maximum displacement difference between two cases with 100 kg TNT was 15.9 mm at the 4th floor. Also the columns D/C ratio of the model in case two was less than that in case one, but in general the model cannot resist more than 100 kg TNT charge weight at 4.5 stand-off distance, because of the columns D/C ratio for two cases was near to 1 at the 1st story.

REFERENCES:

1. HrvojeDraganić, Vladimir Sigmund,(2012), Blast loading on structures. Tehničkivjesnik, , 643-652.
2. Ngo, T.; Mendis, P.; Gupta,A.; Ramsay, J.,(2007), Blast Loading and Blast Effects on Structures – An Overview. // EJSE Special Issue: Loading on Structures
3. Unified Facilities Criteria (2008), "UFC 3-340-02 Structures to Resist the Effects of Accidental Explosions", U.S. Army Corps of Engineers, Naval Facilities Engineering Command, Air Force Civil Engineer Support Agency.
4. Baker W.E., (1973) "Explosions in Air", Univ. of Texas Press, Austin TX USA.
5. Brode H. L., (1955) "Numerical solution of spherical blast waves", Journal of AppliedPhysics, American Institute of Physics, New York.
6. Newmark N.M., Hansen R.J., (1961) "Design of blast resistant structures", Shockand Vibration Handbook, Vol.3, Eds. Harris &Crede, McGraw-Hill, New York.
7. Mills C. A. (1987) "The design of concrete structures to resist explosions and weapon effects". Proceedings of the 1st Int. Conference on concrete for hazard protections, Edinburgh, UK.
8. Vasilis KARLOS, George SOLOMOS, 2013, Calculation of Blast Loads for Application to Structural Components, Administrative Arrangement No JRC 32253-2011 with DG-HOME Activity A5 - Blast Simulation Technology Development.
9. CSI Analysis References Manual forSAP2000, ETABS, and SAFE, April 2009.
10. British standard code, BS 5950-1:2000, Structural use of steelwork in building. BSI 2008.