Non-Linear Dynamic Analysis of Multy Storied Structure Subjected To Blast Load

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Abstract- *The increase in the number of terrorist attacks has shown that the effect of blast loading on structures is a serious matter that should be taken into consideration in the design process. The blast pressure on the structure due to nearby explosion is of very high magnitude and very short duration. Such an impulsive loading requires dynamic time-history analysis. This paper describes the nature of explosion of explosive materials and dynamic pressure developed on the nearby structure in lieu of explosion. Initially, efforts have been made to determine the effect of 1000 kg of C4 explosive material as an equivalent weight of TNT on different surfaces of a building model at a stand-off distance of 22.5m. The intensity of blast load on each surface is analytically determined as a record of pressure time history. Further attempts have been made to determine the effect of distance of blast for the same explosive material on building surfaces at stand-off distance of 10m, 15m, 22.5m and 30m. From the analysis, it is observed that the effect of blast load on front and rear surface of the building is critical. For close range explosions, deformations on front surface are more but with increase in stand-off distance, maximum deformations occur in roof surface. It is also observed that the maximum deformation on the structure due to explosion is directly proportional to the heat of detonation of the corresponding explosive.*

Keywords- Blast loading; TNT; pressure-time history; Stadd pro.v8i; standoff distance

I. INTRODUCTION

Over the last few decades considerable attention has been raised on the behavior of engineering structures under blast or impact loading. The use of explosives by terrorist groups around the world that target civilian buildings and other structures is becoming a growing problem in modern societies. Structural engineering is a field that has entered into this arena to reduce losses and examine the nature of the phenomenon and its effects on buildings where people gather and are the target of such attacks. In addition to these studies, some researches have been conducted on issues related to non-terrorist and accidental explosions as well as side phenomena of explosion.[5]

Extensive research into structural analysis considering blast effects and techniques to protect buildings has been initiated in many countries to build up methods for protecting critical infrastructure and the built environment. There are a number of means available to prevent a booming terrorist attack on a building. Structures analysed for blast loads are subjected to entirely different types of load than that considered in conventional design. Here structures are subjected to quickly moving shock wave which may exert pressures many times greater than those experienced under the greatest of hurricanes. However, in blast phenomenon, the peak intensity lasts for a very small duration only. [3]

Disasters such as the terrorist bombings of the U.S. embassies in Nairobi in 1998, 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 structure subjected to blast loads [10]. The blast occurred at the basement of World Trade Centre in 1993 has the charge weight of 816.5 kg tri-nitro-toluene (TNT).The Oklahoma bomb in 1995 has a charge weight of 1814 kg at a standoff of 5 m [3]. It has been seen that the terrorist attacks ranges from hand bag to truck bombing as in case of Oklahoma City. Hence to provide adequate protection against explosions, the design and construction of public buildings are receiving renewed attention of structural engineers.[2][5]

Blasts that result from bomb explosions have become a new threat to buildings designed for normal static loads. Thus a better understanding of the behaviour of buildings under blast loads is of prime importance, because there are many buildings that may be under threat of blast loading although not originally designed for the same.[2]

II. BACKGROUND

Explosions And Blast Phenomenon :

A. Nature of Explosion :

An explosion can be defined as a very fast chemical reaction involving a solid, dust or gas, during which a rapid release of hot gases and energy takes place. The phenomenon lasts only some milliseconds.

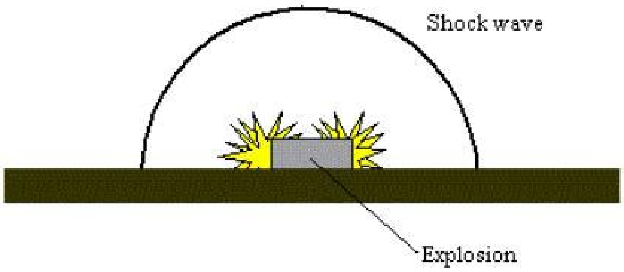


Figure 1: Free Field Blast

The explosion is a phenomenon of rapid and abrupt release of energy. An explosion in air generates a pressure bulb, which grows in size at supersonic velocity. The resulting blast wave releases energy over a small duration and in a small volume, thus generating a pressure wave of finite amplitude, travelling radially in all directions. Explosive is widely used for demolition purposes in construction or development works[2][9]..

B. Blast Wave Pressure – Time History :

The pressure surrounding the element is initially equal to the ambient pressure Po, and it undergoes an instantaneous increase to a peak pressure Pso at the arrival time tA, when the shock front reaches that point. The time needed for the pressure to reach its peak value is very small and for design purposes it is assumed to be equal to zero. The peak pressure Pso is also known as side-on overpressure or peak overpressure. After its peak value, the pressure decreases with an exponential rate until it reaches the ambient pressure at tA+to, to being called the positive phase duration. The negative phase has minimum pressure value is denoted as Pso- and its duration as to-.

The following form of Friedlander’s equation has been proposed, and is widely used to describe this rate of decrease in pressure values: [6].

$$P_s(t) = P_{so}\left(1-\frac{t}{t_o}\right)e^{-b\frac{t}{t_o}}$$

where, Pso is the peak overpressure,

to 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.

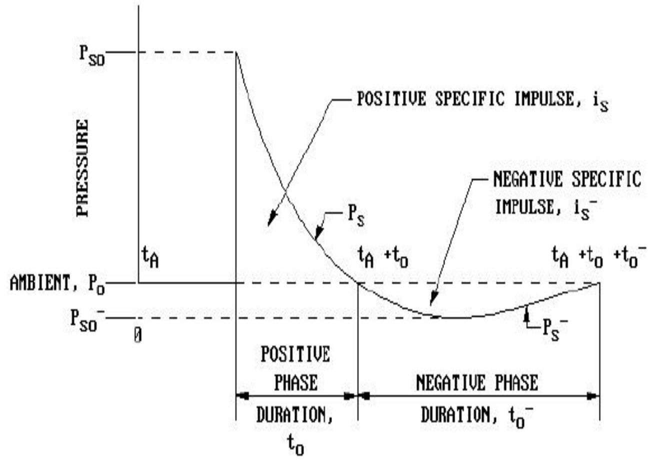


Figure 2: Blast Wave Pressure

C. Blast effect associated with positive and negative phase:

The threat for a conventional bomb is defined by two equally important components, the bomb size or charge weight W and the standoff distance Z between the blast source and the target. The pressure-time profile, two main phases can be observed; part above ambient pressure is called duration of positive phase to while below the ambient is called negative phase duration. Negative phase is of longer duration and a lower intensity then the positive duration. As the standoff distance increases, the duration of positive phase blast increases resulting in a lower-amplitude and longer-duration shock pulse. During negative phase the structures are subjected to suction forces, which is the reason why sometimes during blast loading glass fragments from failures of facade are found outside a building instead in of inside. During negative phase weakened structure may be subjected to impact by debris that may cause additional damage.

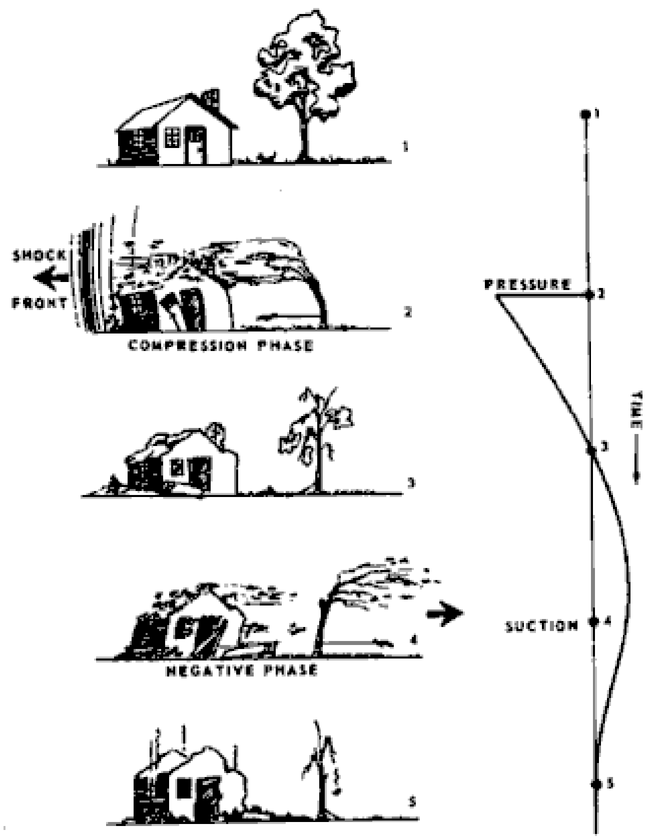


Figure 3: variation of blast effect associated with positive and negative phase

III. OBJECTIVE

1) To calculate blast load for Bare frame with and without shear wall & also for pre-stressed building as per JRC specification
2) To analyze and compare Bare frame with and without shear wall & also for pre-stressed building under blast loading by Time history method.
3) To study effect of 1000kg C4 & 1500kg C4 charge at 22.5 m &15m blast standoff distance for building.
4) To compare response of building with and without shear wall and also with pre-stress in terms of displacement, velocity and acceleration.

IV. LITERATURE REVIEW

- **Quazi kashif et al.**

In this paper, the work is carried out on 'Effect of blast on RCC frame structure'. In this paper they studied the effect of blast loading on a five storey RCC building. Effect of variable blast source weight is calculated by considering 30 m distance from point of explosion. The blast load is calculated from IS 4991-1968. The blast load was analytically determined as a pressure-time history & numerical model of structure was created inSAP2000. The influence of lateral load due to blast load in terms of peak deflection, velocity, acceleration and inter-storey drift is calculated & compared

- **Hrvoje draganic et al.**

In this paper, the work is carried out on 'Blast load on structure'. The work is carried out on blast load calculation and it's effect on structure. The blast load was analytically determined as a pressure-time history & numerical model of structure was created in SAP2000. The detail analysis consist of several step a) estimate of risk; b) load according to estimated hazard; c) analysis of structural behavior. The analysis is also carried out by sudden removal of column considering total destruction of column. The main aim was to check demanded ductility of structure & to compare with available one. The deformation is also checked for the limits

- **Sarita Singla et al.**

In this paper, the work carried out on 'Dynamic response of a space framed structure subjected to blast load'. Blast pressures for different cases are computed using correlation between blast pressure and blast scaled distance based on charts given in U.S manual. Time history loading is also obtained with parameters of reflected total over pressure and duration of positive phase of blast. Computation of blast loading for a three storied framed building has been carried out for the three cases of blast loading. Three categories of buildings are considered as per IS code 4991:1968 for blast resistant designing purposes. The equivalent TNT charge weight W has been taken as 100 Kg, 200 kg & 300 kg and the actual effective distance from explosion i.e. R is taken as 20 m, 30 m, and 40 m. Effect of peak static pressure and peak reflected overpressure of above cases were calculated and compared.

V. DESIGN CONSIDERATION

Determining factors for blast parameter

- Explosive charge weight
- Stand-off distance

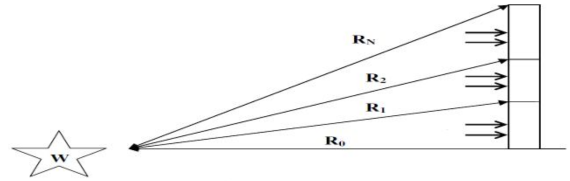


Figure 4: Explosive charge weight(W) and Stand-off distance(R)

- Scaled distance

This is the distance from the source of explosion at which the blast effect caused by standard charge weight is just equivalent to as caused by ‘W ’ charge at distance ‘R’.

- Blast pressure and parameters of blast.

These relationships can be readily programmed and Figures 5 show the diagrams of blast parameters for the positive phase of the blast wave for surface bursts. These diagrams are the metric-units. They are overall more comprehensive and the curves have been drawn with respect to scaled distances from Z = $0.05 m/kg^{1/3}$ to Z = $40 m/kg^{1/3}$. From these diagrams in order to obtain the absolute value of each parameter, its scaled value has to be multiplied by a factor $W^{1/3}$so as to take into account the actual size of the charge. Pressure and velocity quantities are not scaled.

Blast pressure and parameter are calculated from graph which are as bellow

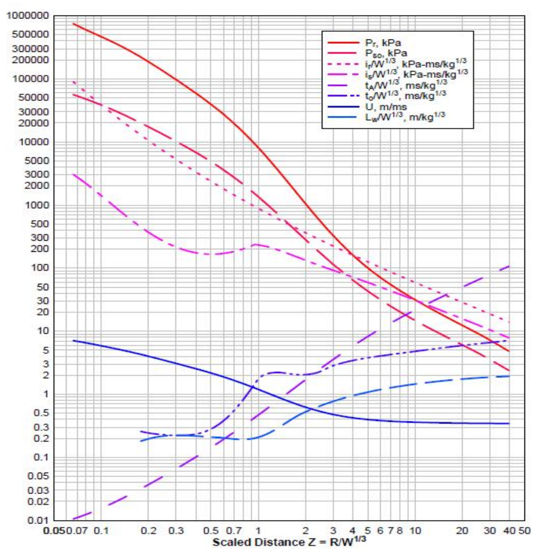


Fig -5: Parameters of positive phase of shock wave of TNT charges from surface bursts

where, U = shock wave speed (m/ms)

Lw = blast wavelength (m)

Pso = maximum incident overpressure (kPa)

Pr = maximum reflected overpressure (kPa)

ir = impulse corresponding to maximum reflected overpressure (kPa-ms)

is = impulse corresponding to maximum incident overpressure (kPa-ms)

ta= arrival time of the blast (ms)

to= duration of positive phase of the blast (ms)

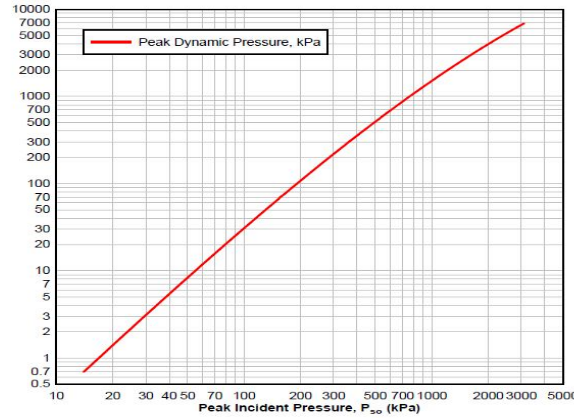


Figure 6: Variation of peak dynamic pressure versus peak incident pressure

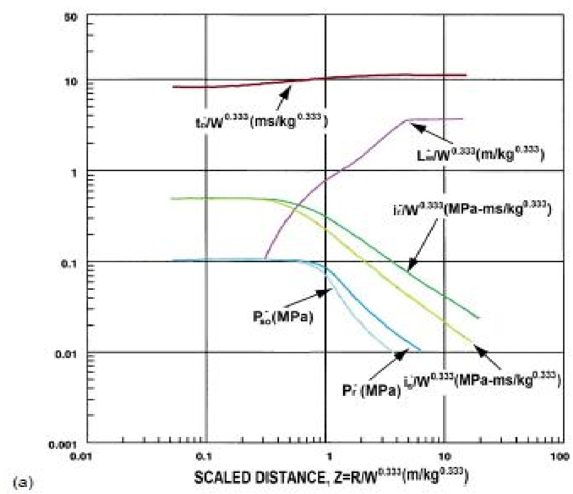


Fig -7: (a) Parameters of negative phase of shock TNT charges from spherical free air bursts

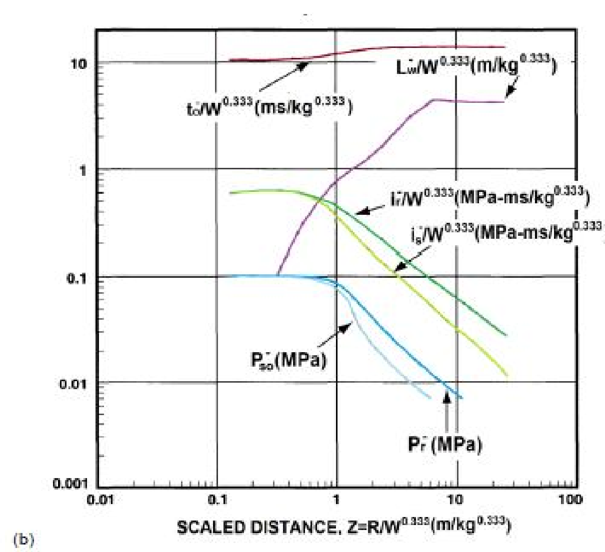


Fig -7: b) Parameters of negative phase of shock wave of wave TNT charges from semispherical surface bursts

VI. ANALYTICAL INVESTIGATION

A. Modeling of frame

The space frame building is modeled in STAAD-Pro. The beams and columns are modeled as beam elements and the slab is modeled as a plate element.

Beam Size: 230 X 500 mm
Column Size: 230 X 600 mm
Slab Thickness :150 mm
Storey Height:3m
Grade of concrete:M25
Explosive type: C4 type of explosive

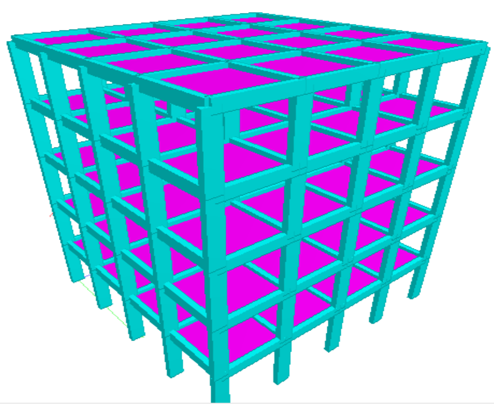


Figure 8: Four Story RCC Bare Frame structure

We taking same model and applying two pair of shear walls as shown bellow

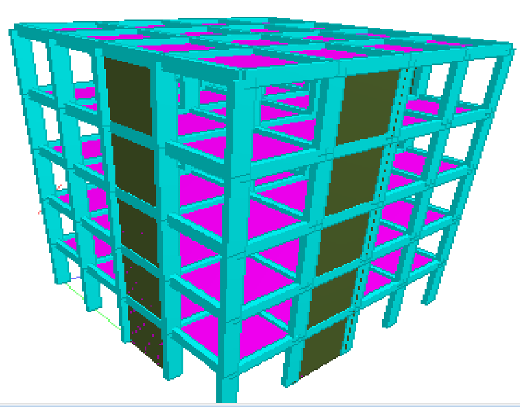


Figure 9: Four Story RCC Bare Frame with shear walls

B. Time History Analysis:

Analysis of a structure, applying data over increment time steps as a function of :
–Acceleration
–Force
–Moment, or
–Displacement

The most general approach for solving the dynamic response of structural systems is direct numerical integration of the dynamic equilibrium equations. For most real structures which contain stiff elements, a very small time step is required to obtain a stable solution. Reducing the integration time step will increase the accuracy, and generally a time step size which is less than 0.01 times the dominating period is selected.

To get consistent results for the 3D building models, the time step had to be reduced to 0.001sec. The non-linear direct integration time history analyses were run for a duration of 2 s with 2000 time steps for all the buildings, and encompassed one cycle of structural response.

schematically the recommended procedure for constructing the pressure time history of a blast wave acting on the front face of a building.

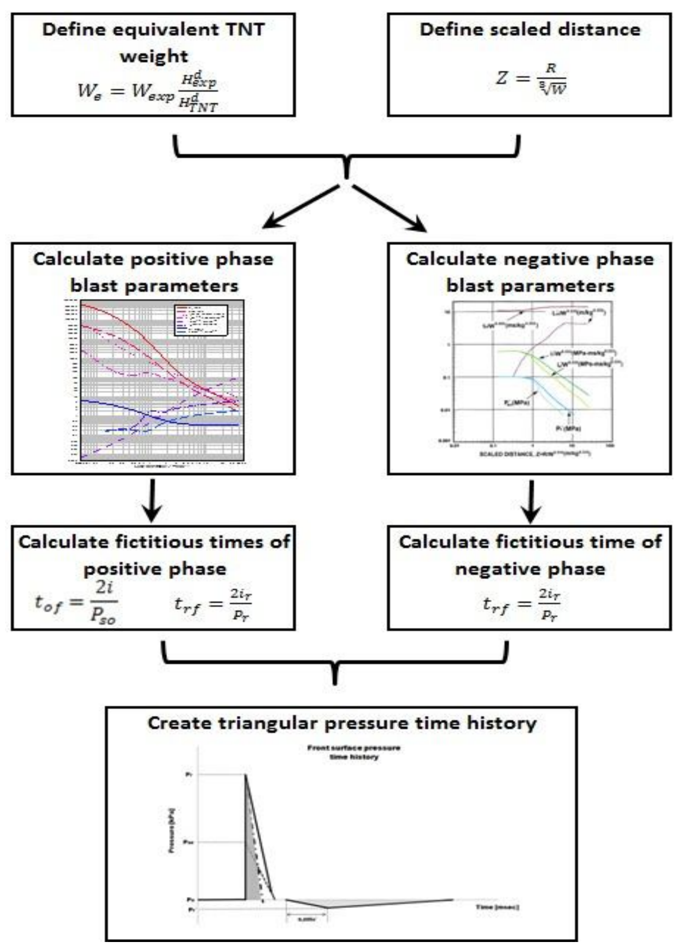
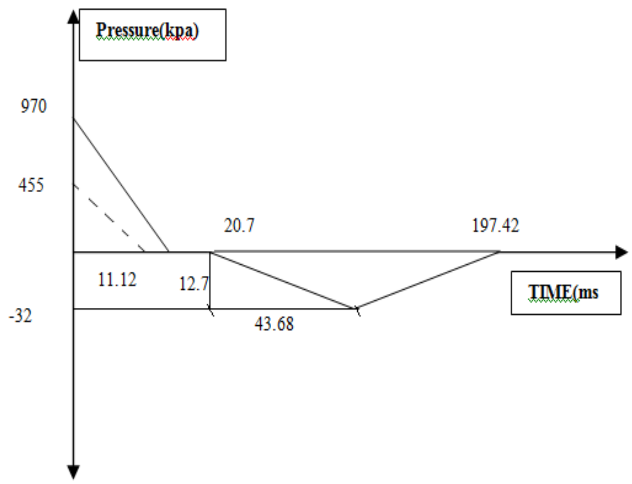
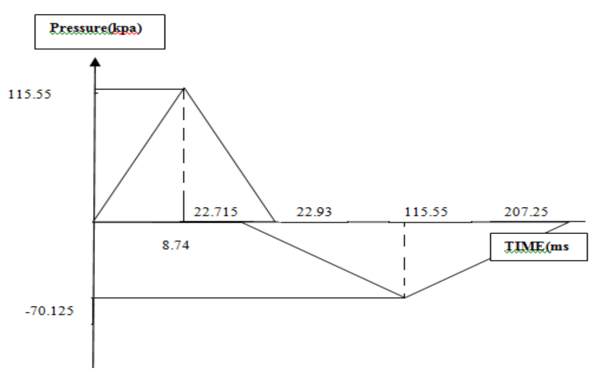


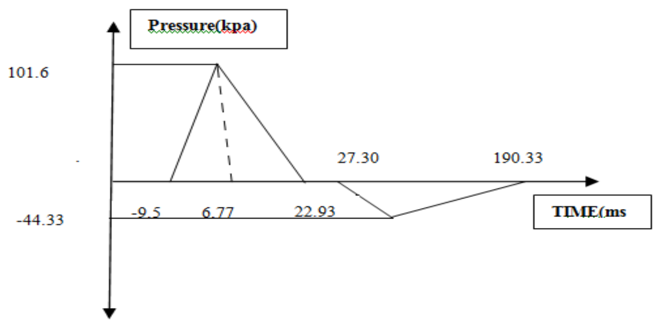
Fig -10 : Diagram of constructing the pressure time history of a blast wave.



(a)



(b)



(c)

Fig -11: Blast pressure time history at the (a) front surface (b)roof and side surface (c) rear surface of the structure

VII. RESULT AND DISCUSSION

In the model, the coordinate system has been considered as the length of the structure along X- direction, width along Z -direction and height of the structure along Y direction. The building is modeled in STAAD.Pro and analysis is carried out.

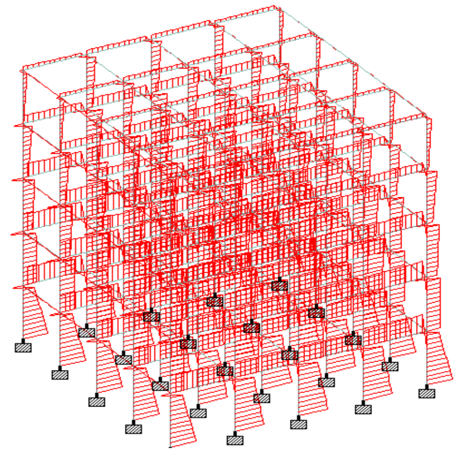


Fig No.12 bending moment digram

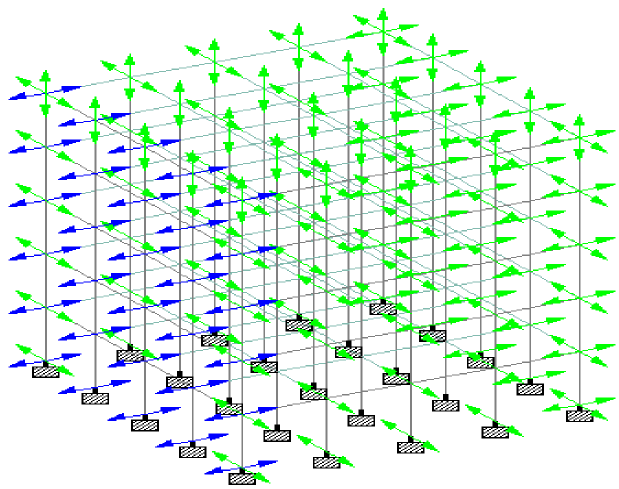


Fig.12 Direction of force acting on structure

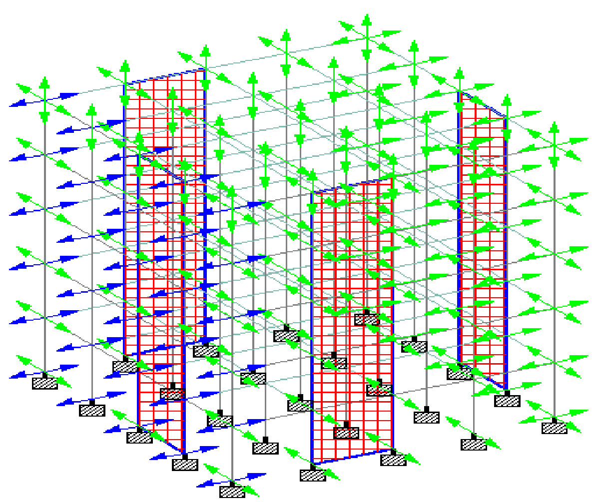


Fig.12 Direction of force acting on structure

Table 1 frequency & period of structure

Mode	Frequency Hz	Period seconds
1	1.564	0.639
2	2.49	0.402
3	2.81	0.356
4	4.634	0.216
5	7.524	0.133
6	7.652	0.131

The effect of 1000kg of C4 explosive located at 22.5m from front surface of the building was observed and presented in the following section. The maximum deformation of the front surface occurs at 3.7m from the bottom of the building. The time-displacement relation is presented in figure

The result of bare frame structure in the form of disp. Vs. time, Vel. Vs. time and Accel. Vs. time are as follows

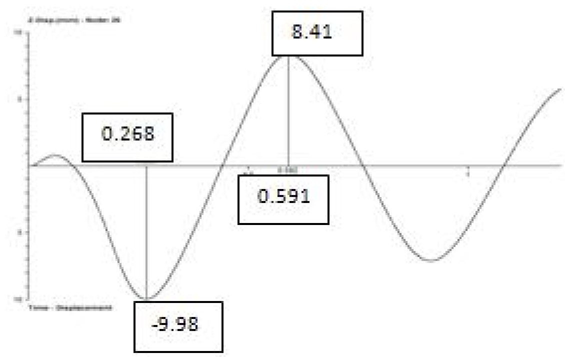


Figure 13: Displacement vs. time

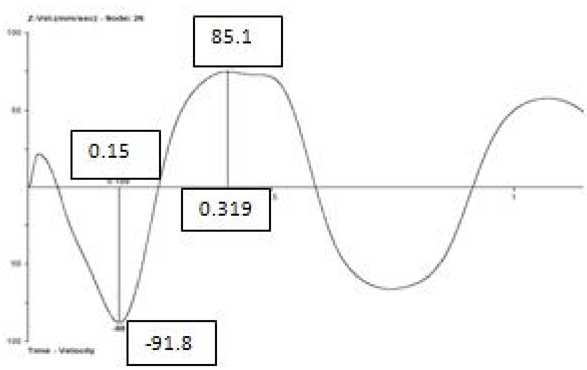


Figure 14: Velocity vs. time

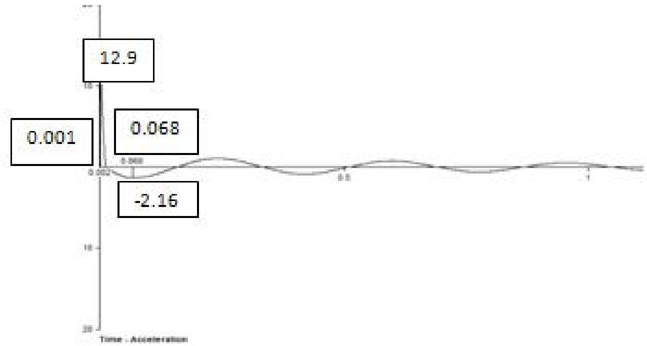


Figure 15: Acceleration vs. time

The result of bare frame structure with shear wall in the form of disp. Vs. time, Vel. Vs. time and Accel. Vs. time are as follows

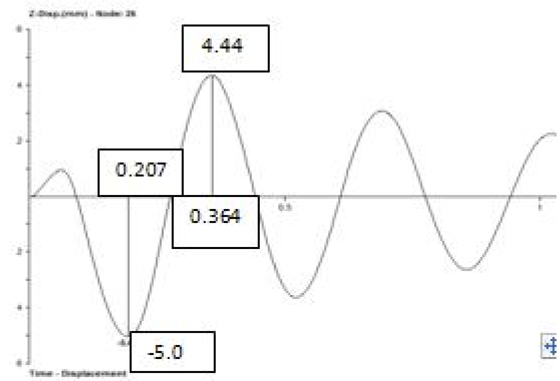


Figure 13: Displacement vs. time

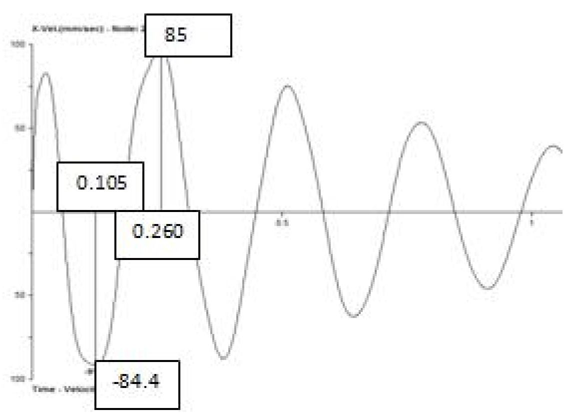


Figure 14: Velocity vs. time

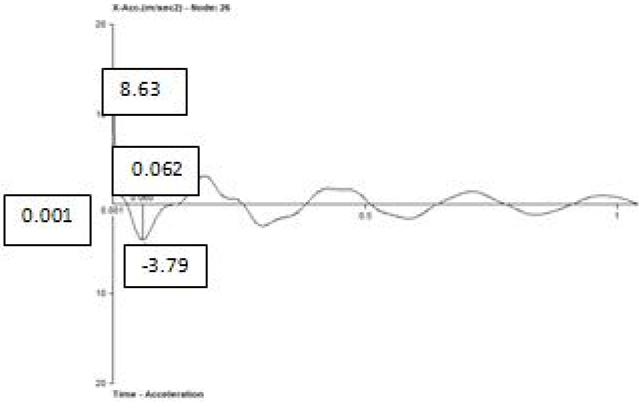


Figure 15: Acceleration vs. time

Result Comparison for 1000kg C4

Response	1000 kg C4 @22.5m	Bare Frame	Bare frame with shear wall	Comparison of Result (%)
Displacement (m)		0.00998	0.0050	49.39
Velocity (m/sec)		0.09180	0.0850	7.4
Acceleration (m/sec^2)		12.9	8.63	33.10

Result Comparison for 1500kg C4

Response	1500 kg C4 @22.5m	Bare Frame	Bare frame with shear wall	Comparison of Result (%)
Displacement (m)		0.0144	0.00968	32.77
Velocity (m/sec)		0.223	0.196	12.10
Acceleration (m/sec^2)		11.4	8.66	24.04

Result Comparison for 1000kg C4

Response	1000 kg C4 @15m	Bare Frame	Bare frame with shear wall	Comparison of Result (%)
Displacement (m)		0.0116	0.00865	25.43
Velocity (m/sec)		0.147	0.133	9.52
Acceleration (m/sec^2)		28	18.8	32.85

Result Comparison for 1500kg C4

Response	1500 kg C4 @15m	Bare Frame	Bare frame with shear wall	Comparison of Result (%)
Displacement (m)		0.0139	0.0105	24.46
Velocity (m/sec)		0.1980	0.176	11.11
Acceleration (m/sec^2)		35.1	23.6	32.76

VIII. CONCLUSION

The explosion near the structure can cause catastrophic damage to the structure, hence these loads should be considered in design. It is not economical to design buildings for blast loading. In the present study, extensive work is carried out for blast loads and its effects on building structures. Building model is developed under blast load and analysis is carried out using STAAD-Pro. On the basis of the present study, the following conclusions may be drawn.

- The blast pressure and the corresponding displacements on the structure increases with increase in charge weight and decrease in the stand-off distance.
- The maximum deformations are obtained on the front and the roof surface of the structure.
- Effect of blast load on prestress structure is same as bare frame structure.
- For 1000 kg C4 explosive at stand-off distance 22.5m, due to shear wall there is 49.39%, 7.5% & 33.10% reduction in displacement, velocity and acceleration respectively
- For 1500 kg C4 explosive at stand-off distance 22.5m, due to shear wall there is 32.77%, 12.10% & 24.04% reduction in displacement, velocity and acceleration respectively
- For 1000 kg C4 explosive at stand-off distance 15m, due to shear wall there is 25.43%, 9.52% & 32.85% reduction in displacement, velocity and acceleration respectively.
- For 1500 kg C4 explosive at stand-off distance 15m, due to shear wall there is 24.46%, 11.11% & 32.76% reduction in displacement, velocity and acceleration respectively
- On an average due to shear wall there is 33.01%, 10.3% & 30.68% reduction in displacement, velocity and acceleration respectively
- For close range explosions displacements on the front surface are critical but as the distance from the structure

increases the displacements on the roof surface are critical for the building model.

- The variation of displacements along the length and width of the front, rear, roof and side surfaces of the structure are approximately sinusoidal in nature with maximum displacements around the center of the surface

IX. ACKNOWLEDGMENT

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REFERENCES

[1] Sarita Singla, Pankaj Singla, Anmol Singla, "Computation of blast loading for a multi storeyed framed building."

[2] Effect of Blast on G+4 RCC Frame Structure, International Journal of Emerging Technology and Advanced Engineering. Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 4, Issue 11, November 2014)

[3] M. V. Dharaneepathy, M. N. Keshava Raot and A. R. Santhakumarzf, " Critical Distance for Blast-resistant Design", Computer and Structures vol.54: pp.587-595 (1995).

[4] Suraj D Bhosale & Shrinivas.R. Suryawansh "Dynamic Analysis of RCC Frame Structure subjected to Blast Loading without Infilled Wall in Multi Storey Building."

[5] IS Code IS: 4991-1968 — "Criteria for blast resistant design of structures for explosion above ground", Bureau of Indian Standards (1968)

[6] JRC Technical report "Calculation of Blast Loads for Application to Structural Components"

[7] Draganic, H. & Sigmund, V., "Blast Loading On Structures." Hrvoje Draganic, Vladimir Sigmund ISSN 1330-3651

[8] T. Ngo, P. Mendis, A. Gupta and J. Ramsay Blast Loading and Blast Effects on Structures – An Overview, EJSE special issue: loading on structures (2007)

[9] P. Mendis and T. Ngo Vulnerability Assessment of Concrete Tall Buildings Subjected to extreme loading conditions, Proceedings of the CIB-CTBUH international conference on Tall buildings (2003)