Effect of Blast Load on Soft Storey Building

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Abstract— The number of terrorist activity have increased concern about safety of building. So, it's became need to design building for blast load. This study compares the response of 3 dimensional soft storey building with Bare frame under blast loading. To design and analyse a structure for blast loading require a deep understanding of blast phenomena. The blast load was calculated by using IS code. This paper present numerical example of fictive structure exposed to blast load. Effect of variable blast source weight is calculated for 30m standoff distance. The blast load is analytically determined as pressure-time history and numerical model was created in SAP2000 for frame and soft storey building. The result shows that due to infill there is significant reduction in displacement, velocity and acceleration. The influence of blast load in terms of peak deflection, velocity and acceleration is determined and compared.

Keywords- *Blast Loading ; pressure-time history; Standoff distance*

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I. INTRODUCTION

Following the increased terrorist attacks in the past decade and consequently many human and financial losses to the international community, extensive studies are underway on the phenomenon. 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 researchers have been conducted on issues related to non-terrorist and accidental explosions as well as side phenomena of explosion.[14]

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. Under blast loading, buildings are subjected to the loads that are quite different from those governing their primary design in both magnitude and direction. Thus a better understanding of the behavior 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]

A. Explosions And Blast Phenomenon

An explosion is defined as a large-scale rapid and sudden release of energy. 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].

B. Blast Wave Pressure – Time History

The pressure-time profile, two main phases can be observed portion above ambient is called positive phase of duration while that below ambient is called negative phase of duration. The negative phase is of a longer duration and a lower intensity than the positive duration. During the negative phase, the weakened structure may be subjected to impact by debris that may cause additional damage [2].

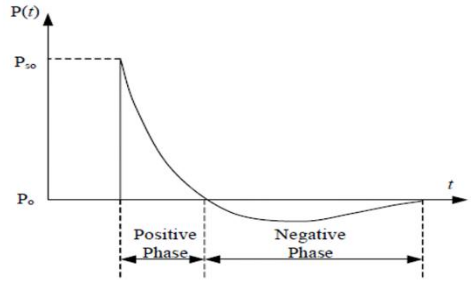

Figure 1: Blast Wave Pressure

C. Plastic Hinges

SAP2000 implements the plastic hinge properties described in FEMA-356.

II. 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 in SAP2000. The influence of lateral load due to blast load in terms of peak deflection, velocity, acceleration and inter-storey drift is calculated & compared.

M. V. Dharaneepathy et al.

They studied the effects of the stand-off distance on tall shells of different heights, carried out with a view to study the effect of distance (ground-zero distance) of charge on the blast response. An important task in blast-resistant design is to make a realistic prediction of the blast pressures. The distance of explosion from the structure is an important datum, governing the magnitude and duration of the blast loads. The distance, known as 'critical ground-zero distance', at which the blast response is a maximum. This critical distance should be used as design distance, instead of any other arbitrary distance.

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.

Jayashree. S. M et al.

In this paper, the work carried out on 'Dynamic response of a space framed structure subjected to blast load'.In this paper attempt was made to use slurry Infiltrated fiber Reinforced Concrete and result are compared with RCC structure. Space framed models were developed and time history analysis was carried out. The properties of RCC and SIFCON were derived from experiment and dynamic characteristics such as fundamental frequency, mode shape are evaluated. The displacement time history responses of frames are compared.

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. 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.

I.N. Jayatilake et al.

In this paper, the work carried out on "Response of tall buildings with symmetric setbacks under blast loading". Study explores three-dimensional non linear dynamic responses of typical tall buildings with and without setbacks under blast loading. The influence of the setbacks on the lateral load response due to blasts in terms of peak deflections, accelerations, inter-storey drift and bending moments at critical locations (including hinge formation) were investigated. Structural response predictions were performed with a commercially available three-dimensional FEA program using non-linear direct integration time history analyses. Results obtained for buildings with different setbacks were compared and conclusions made. The comparisons revealed that buildings having setbacks that protect the tower part above the setback level from blast loading show considerably better response in terms of peak displacement and inter-storey drift, when compared to buildings without setbacks. Abrupt changes in moments and shears are experienced near the levels of the setbacks. Typical twenty storey tall buildings with shear walls and frames that are designed for only normal loads perform reasonably well, without catastrophic collapse, when subjected to a blast that is equivalent to 500 kg TNT at a standoff distance of 10 m.

III. METHODOLOGY

The blast load depends upon two major factors defined by the bomb size or charge weight W, and the standoff distance (R) between the blast source and the target [2]

Consider the buildings subjected to a blast equivalent in yield to some kg of TNT at a certain standoff distance. For dynamic analysis of structures, the blast effects are most conveniently represented by a loading-time history that is applied to the structural members as transient loading. The magnitude and the pressure-time history of the blast load is calculated using the Table 1 given in IS 4991-1968. The method used to calculate the blast load is to divide the front face into a number of well-defined grids and to calculate the total impulse on each grid point. It should be assumed that time varying triangular forces are acting on each beam-column joint on the front face of the buildings. These pulses have zero rise time and decay linearly as shown in Figure.[2][9]

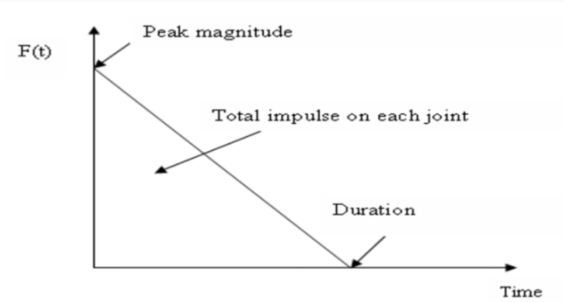

Figure 2: Blast Loading Function

The blast is applied in X direction. The total column-beam joints are on the front face of building. The forces due to blast loading should be applied to the buildings as triangular loading functions calculated separately for each joint of the front face of the building, taking into account the distance to each joint from the source of explosion. Once the reflected pressure at each beam-column joint is calculated it should be multiplied with Tributary area to get the peak load at that joint. Positive time duration can also be find out, now we can generate the Load-Time history of each joint as input to SAP 2000.[2][9]

IV. BLAST LOAD

A. Design Consideration

As the impulse of the negative zone is less than the impulse of the positive zone, the negative face is usually not taken into account for the design purpose.

B. Determining factors for blast parameter

- Explosive charge weight
- Stand off distance

C. 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'.

D. IS Code provision:

As per IS 4991 – 1968, the value of the P_r computed from Table 1 for 1 tonne detonation amount.
The pressure time relationship in the positive phase are idealised by using a straight line starting with the maximum pressure value but terminating at a time t_d.

TABLE I: Blast Parameters For W=100 kg And R = 30 m

FL	D(m)	Z(m)	P	T(ms)	A(sq. m)	F(KN)
1	30.740	66.229	75.17	13.36	4.5	338.265
	30.298	65.276	77.44	13.24	9	696.96
	30.149	64.955	78.28	13.19	9	704.52
	30.298	65.276	77.44	13.24	9	696.96
	30.740	66.229	75.17	13.36	4.5	338.265
2	31.176	67.168	73.64	13.43	4.5	331.38
	30.740	66.229	75.17	13.36	9	676.53
	30.594	65.913	75.77	13.33	9	681.93
	30.740	66.229	75.17	13.36	9	676.53
	31.176	67.168	73.64	13.43	4.5	331.38
3	31.890	68.705	71.12	13.55	4.5	320.04
	31.464	67.787	72.62	13.48	9	653.58
	31.320	67.478	73.13	13.46	9	658.17
	31.464	67.787	72.62	13.48	9	653.58
	31.890	68.705	71.12	13.55	4.5	320.04
4	32.863	70.801	67.69	13.74	4.5	304.605
	32.449	69.911	69.14	13.6	9	622.26
	32.310	69.611	69.63	13.63	9	626.67
	32.449	69.9113	69.14	13.6	9	622.26
	32.863	70.801	67.69	13.74	4.5	304.605
5	34.073	73.409	63.43	14.04	4.5	285.435
	33.674	72.550	64.82	13.93	4.5	291.69
	33.541	72.261	65.3	13.9	4.5	293.85
	33.674	72.550	64.82	13.93	4.5	291.69
	34.073	73.409	63.43	14.04	4.5	285.435

Similarly, blast loads are calculated for 200kg, 300kg & 400kg of TNT charge weight for 30 m standoff distance.

TABLE II : Blast Parameters For W=500 kg And R = 30 m

FL	D(m)	Z(m)	P	T(ms)	A(m^2)	F(KN)
1	30.740	38.731	227.81	15.14	4.5	1025.145
	30.298	38.173	236.42	14.96	9	2127.78
	30.149	37.986	239.34	14.89	9	2154.06
	30.298	38.173	236.42	14.96	9	2127.78
	30.740	38.731	227.81	15.14	4.5	1025.145
2	31.176	39.280	220.82	15.31	4.5	993.69
	30.740	38.731	227.81	15.14	9	2050.29
	30.594	38.546	230.73	15.08	9	2076.57
	30.740	38.731	227.81	15.14	9	2050.29
	31.176	39.280	220.82	15.31	4.5	993.69
3	31.890	40.179	211.8	15.54	4.5	953.1
	31.464	39.642	217.18	15.4	9	1954.62
	31.320	39.461	219	15.36	9	1971
	31.464	39.642	217.18	15.4	9	1954.62
	31.890	40.179	211.8	15.54	4.5	953.1
4	32.863	41.405	199.33	15.87	4.5	896.985
	32.449	40.884	204.61	15.73	9	1841.49
	32.310	40.709	206.43	15.68	9	1857.87
	32.449	40.884	204.61	15.73	9	1841.49
	32.863	41.405	199.33	15.87	4.5	896.985
5	34.073	42.929	183.93	16.37	4.5	827.685
	33.674	42.427	188.99	16.18	4.5	850.455
	33.541	42.259	190.72	16.12	4.5	858.24
	33.674	42.427	188.99	16.18	4.5	850.455
	34.073	42.929	183.93	16.37	4.5	827.685

V. ANALYTICAL INVESTIGATION

A. Modeling of frame

The space frame building is modeled in SAP 2000. The beams and columns are modeled as frame elements and the slab is modeled as a shell element. The bottom of the frame is fixed. masonry infill walls are modeled as equivalent compressive diagonal struts along the loaded diagonal using beam elements. The diaphragm action is considered at every floor level.3D model of the frame building will be done using SAP.[4]

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.[8]

To get consistent results for the 3D building models, the time step had to be reduced to 0.001 s. 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.[8]

C. Numerical Experiment

- For building without infill
  As a study five story frame reinforced concrete symmetrical structure with 3 m and 4 bays each side is used. The story height kept 3 m. The compressive strength of concrete is 30 MPa. The blast of 100 kg 200kg, 300kg 400kg and 500 kg is applied at 30 m distance.[2]

- For building with soft storey
  As a study five story frame reinforced concrete symmetrical structure with 3 m and 4 bays each side was used. The story height kept 4 m for 2 storey and remaining storey are kept as 3 m. The compressive strength of concrete is 30 MPa. The blast of 100 kg 200kg, 300kg 400kg and 500 kg is applied at 30 m distance. The equivalent width of strut is 1.015 m.

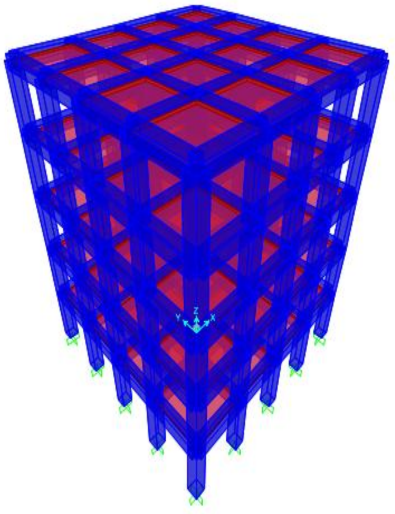

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Figure 3: Five Story RCC Frame Building

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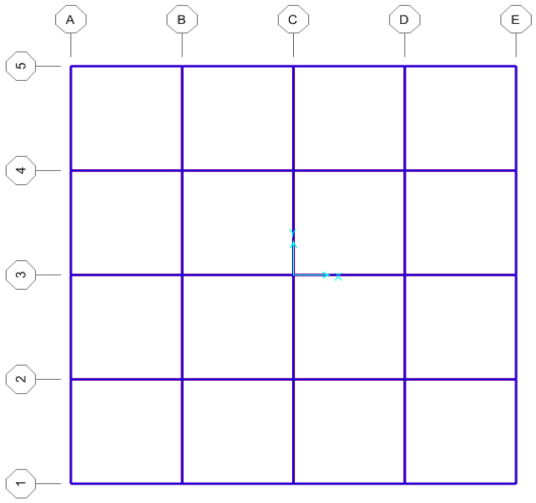

Figure 4: Plan

V. RESULTS

The loads are given as inputs to the software and time history analysis is carried out by considering non-linearity and response up to 2 second are drawn. After analyzing the plot results appeared for the top joint of frame for charge weight 100kg, 200kg, 300kg, 400kg & 500kg of TNT at 30 m distance from point of explosion for building (with and without soft storey) are shown in figures below

Blast performance evaluation is a complex phenomena as there are several factors affecting the behavior of the building. Some of the factors affecting the behavior of building are scaled distance and charge weight. It can be clearly seen from figures that for higher blast loads, magnitude of impact is more, however the duration of its action on the structure in lesser. As the charge increases, the displacement amplitude should also increase, however, from displacement vs time plot for various charge weights it can be observed that the amplitude of vibration has not increased linearly. This is due to the reason that the response depends on three factors viz., pressure, arrival time and positive time duration. Even though the pressure is high, its arrival time and duration are low.

The top and maximum response values of all buildings obtained from the analyses are presented in figures. Typical time history obtained for top storey acceleration is shown in Fig acceleration vs time plot. The maximum acceleration response occurs immediately after the blast, while the maximum displacement occurs at a later stage in the time history. Careful observation of displacement time histories reveals that for all considered cases, the building has a more regular variation of displacement.

A. Plot Functions of RCC frame for 100 Kg TNT were plotted below.

1) Plot function of Displacement vs. time :

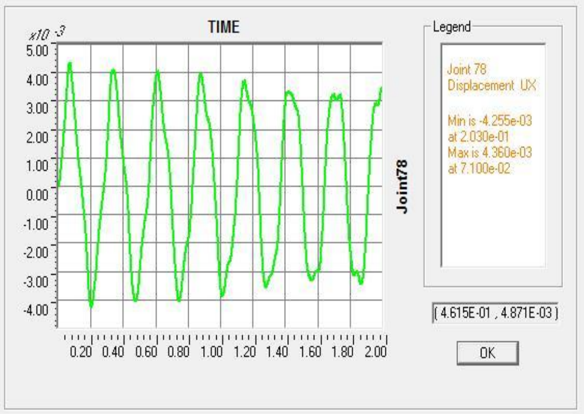

Figure 5: Displacement vs. time

2) Plot function of Velocity vs. time:

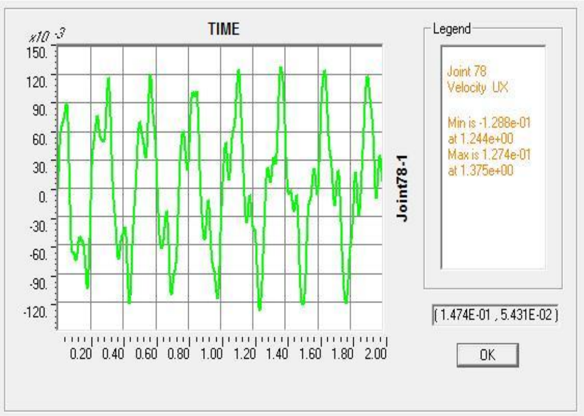

Figure 6: Velocity vs. time

3) Plot function of Acceleration vs. time:

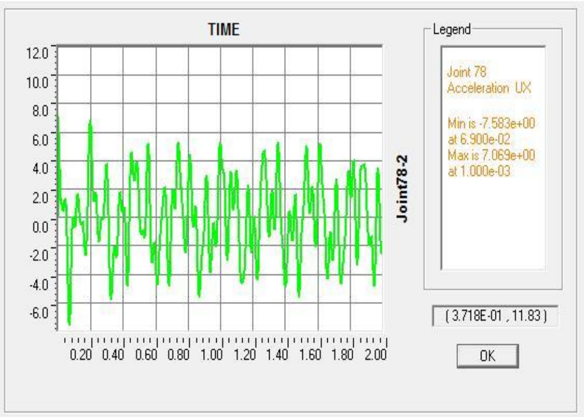

Figure 7: Acceleration vs. time

B. Plot Functions of RCC frame for 500 Kg TNT were Plotted Below.

1) Plot function of Displacement vs. time:

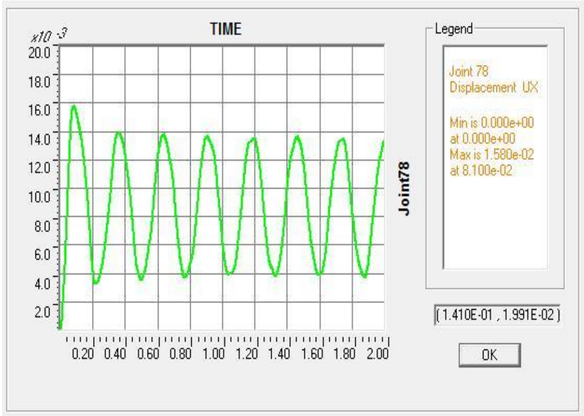

Figure 8: Displacement vs. time

2) Plot function of Velocity vs. time :

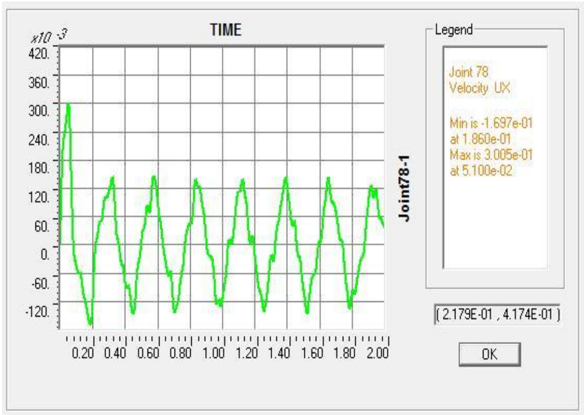

Figure 9: Velocity vs. time

3) Plot function of Acceleration vs. time:

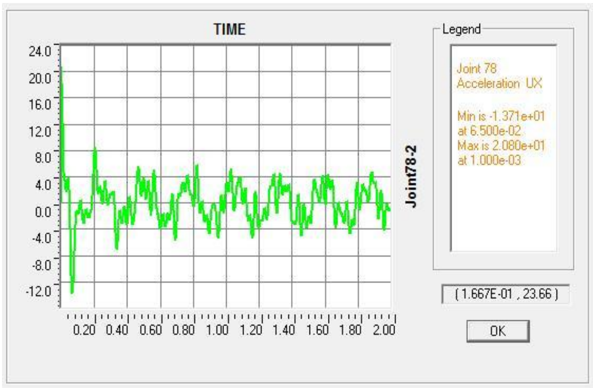

Figure 10: Acceleration vs. time

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C. Plot Functions of soft storey building 100 Kg TNT were plotted below.

1) Plot function of Displacement vs. time :

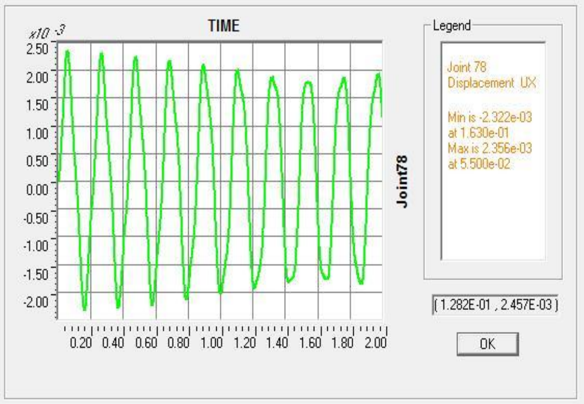

Figure 11: Displacement vs. time

2) Plot function of Velocity vs. time:

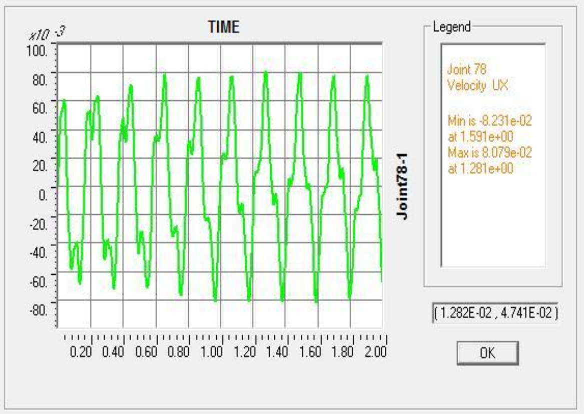

Figure 12: Velocity vs. time

3) Plot function of Acceleration vs. time:

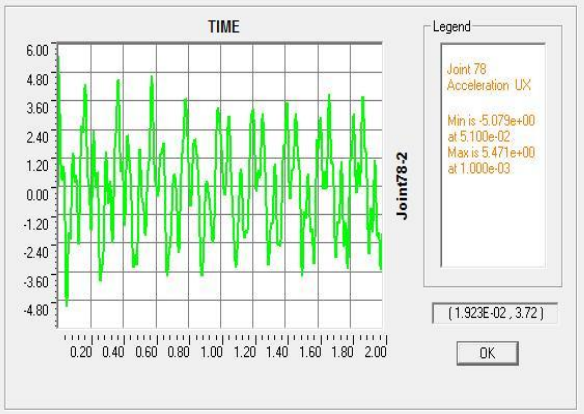

Figure 13: Acceleration vs. time

D. Plot Functions of soft storey building 500 Kg TNT were plotted below.

1) Plot function of Displacement vs. time:

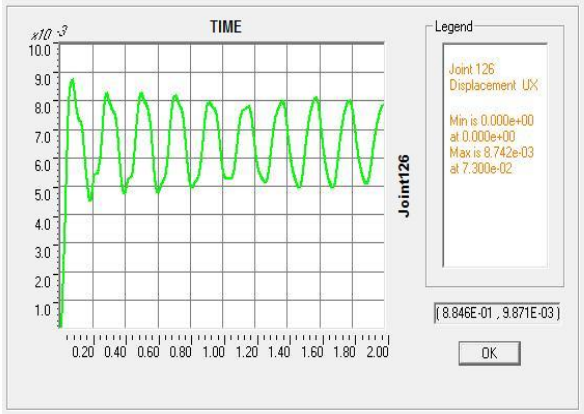

Figure 14: Displacement vs. time

2) Plot function of Velocity vs. time :

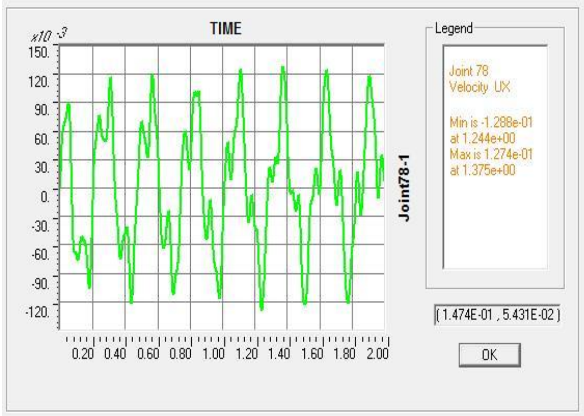

Figure 15: Velocity vs. time

3) Plot function of Acceleration vs. time:

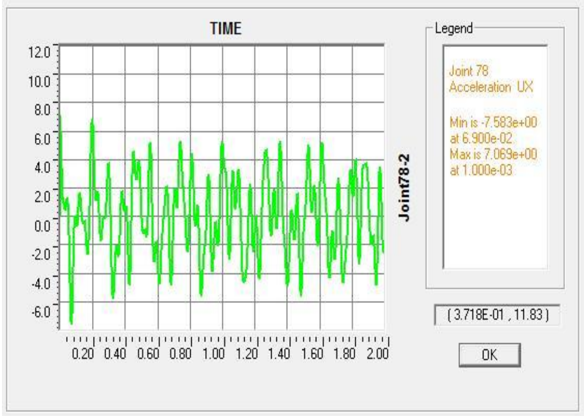

Figure 16: Acceleration vs. time

E. Comparison of results.

TABLE III

Response	100 kg TNT	Bare Frame	Soft storey	Comparison (%)
Displacement (m)		0.00436	0.00258	40.82
Velocity (m/sec)		0.1288	0.0823	36.10
Acceleration (m/sec^2)		7.58	5.47	27.83

Response	200 kg TNT	Bare Frame	Soft storey	Comparison (%)
Displacement (m)		0.00734	0.00404	44.96
Velocity (m/sec)		0.1518	0.1019	32.87
Acceleration (m/sec^2)		10.94	8.42	23.03

Response	300 kg TNT	Bare Frame	Soft storey	Comparison (%)
Displacement (m)		0.01012	0.00562	44.44
Velocity (m/sec)		0.205	0.1402	31.60
Acceleration (m/sec^2)		14.24	11.178	21.558

Response	400 kg TNT	Bare Frame	Soft storey	Comparison of Result (%)
Displacement (m)		0.0129	0.0072	44.186
Velocity (m/sec)		0.2548	0.1752	31.24
Acceleration (m/sec^2)		17.43	13.68	21.51

Response	500 kg TNT	Bare Frame	Soft storey	Comparison (%)
Displacement (m)		0.0158	0.0083	47.46
Velocity (m/sec)		0.3	0.2026	32.46
Acceleration (m/sec^2)		20.797	16	23

VI. CONCLUSION

From non-linear dynamic analysis of building subjected to blast load without and with infill (soft storey), following conclusions were drawn.

1. Masonry infill's have significant effect on blast performance of buildings.
2. For 100 kg TNT, due to infill there is 40.82%, 36.10% & 27.83% reduction in displacement, velocity and acceleration respectively.
3. For 200 kg TNT, due to infill there is 44.96%, 32.87% & 23.03% reduction in displacement, velocity and acceleration respectively.
4. For 300 kg TNT, due to infill there is 44.44%, 31.6% & 21.558% reduction in displacement, velocity and acceleration respectively.
5. For 400 kg TNT, due to infill there is 44.186%, 31.24% & 21.51% reduction in displacement, velocity and acceleration respectively.
6. For 500 kg TNT, due to infill there is 47.46%, 32.46% & 23% reduction in displacement, velocity and acceleration respectively.
7. Plastic hinges are formed in all models and are found below collapse level.
8. In soft storey building plastic hinge are formed at ground floor and first floor. But in bare frame plastic hinges are formed in almost all floors. It shows walls have higher resistance to blast load and it also define weak storey of building. .
9. Blast can create significant effect on building. so, it's necessary to design important structure for blast load.

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