Analysis and Design of RCC Structures against Blast Loads

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***Abstract*- Structural safety and integrity has become a great challenge to engineers. With advancement in technology the problem to design the structure for most complex loads have been solved easily. Though, the design of important and high rise structures have been restricted to seismic loads only. In recent years, terrorism has shown its impacts on buildings. Due to these effects the importance to design the structure against blast loads also increased. Blast explosions releases large pressures and heat into air. This phenomenon though it lasts for only milli seconds but have adverse effects on the structures. This paper shows blast resistant analysis and design of a G+7 commercial structure with and without shear walls for a charge weight of 50kg and 100kg TNT at 30m distance in ETABS 2016.**

Index terms- Blast loads, Standoff Zone, Time History, Shear walls

1. INTRODUCTION

Blast can be defined as an explosion which is a very fast chemical reaction during which rapid amount of hot gases and energy gets released. This phenomenon lasts only some milliseconds and results in production of high temperatures and pressures. When a detonation takes place a blast wave containing large amount of energy gets released and moves faster than the speed of the sound. Blast wave is assumed to be spherical and the energy reduces as the wave prolongs further. Blast loads are dynamic loads and have to calculate carefully similar to earthquake and wind loads. Blast loadings are short duration loads hence they can be taken as impulse forces.

2. EXPLOSIVES

Understanding the types and charge weights of the explosives are important for better designing of a structure to resist explosion loads. Explosives are taken in terms of TNT equivalent since it resembles blast characteristics of most of the solid explosives. The overall damage of the structure can be predicted based on the size of the explosion, distance between the explosion and the structure.

Table-1 Estimated quantities of charge weights of explosives in various vehicles

Vehicle type	Charge mass/kg
Compact car trunk	115
Trunk of a large car	230
Closed van	680
Closed truck	2.27
Truck with trailer	13.610

Table-2 various explosives in TNT equivalent

Types of Explosives	TNT equivalent in kg
TNT	1000
RDX	1185
Nitroglycerin	1480
Gelatin	1000
C4	1340
Nitroglycerin dynamite	600

3. STAND OFF DISTANCES

It is one of the most important parameter for the design of blast resistant structures. The distance between point of detonation (source) and the point under consideration (target) is known as standoff distance or standoff zone. From previous studies it has been proved that by an increase in the distance the blast energy

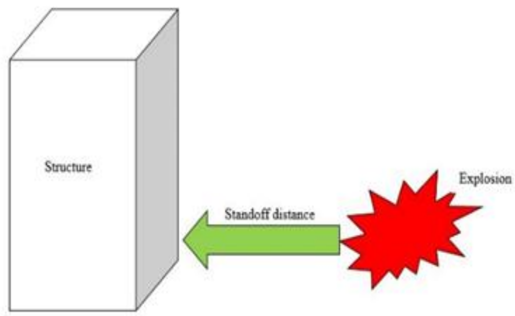


Fig.1 standoff distance

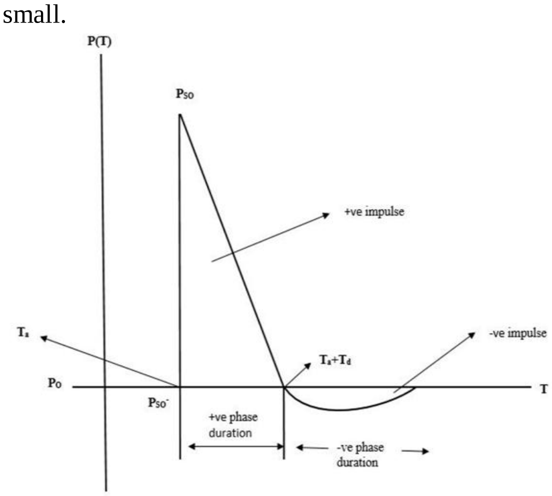
4. BLAST PHENOMENON

When an explosion occurs the pressure initially equal to ambient pressure (Po) will undergo to an instantaneous increase to a peak pressure (Pso) at the arrival time (Ta).

After reaching the peak value, the pressure decreases with an exponential rate until it reaches ambient pressure this phase is called positive phase duration (+ve).

After positive duration the pressure become smaller than the ambient pressure. This phase is known as negative phase duration (-ve).

The negative phase is longer than the positive phase and is neglected in design since their values are very small.



During negative phase the structures are subjected to suction force.

The minimum pressure is denoted as (Pso-) and its duration as (To-).

The pressures below the ambient pressures are considered if the overall performance of the structure is of concern.

5. BLAST LOADINGS

Blast loads are calculated from scaling laws as per IS 4991:1968.

To understand the effect of distance on blast characteristics scaling laws are used. These laws scales the parameters which were defined through experiments in order to be used for varying values of distance and charge energy release.

$$\text{Scaled distance } x = \frac{\text{Actual distance}}{W^{1/3}}$$

$$\text{Scaled Time } t_0 = \frac{\text{Actual Time}}{W^{1/3}}$$

Here,

W = yield of explosion in equivalent weight of reference explosive measured in tonnes i.e.,(weight of the charge in TNT).

x = scaled distance for entering the table1 from IS: 4991 for reading peak values.

t0 = scaled time read from table 1 from IS:4991 against scaled distance.

Actual distance is measured from the ground zero to the point under consideration and actual time is time after explosion.

6. BLAST ANALYSIS AND DESIGN

Blast analysis can be performed using a time history analysis in which the blast load is applied using a triangular function. The function should start with zero initially and ramp up over a small time step then vary linearly from full value to again zero.

Blast pressures act upon a unit area of the member by multiplying these pressures with the corresponding areas gives the required blast loads for a particular stand off distance.

Blast load obained is applied as point loads at one side only.

6.1 MODELLING OF THE STRUCTURE:

The structure is modelled in ETABS 2016 software which is a G+7 commercial building. Initially the structure is designed as per IS456:2000.Dead loads and loads are calculated as per IS875 part-1&2.

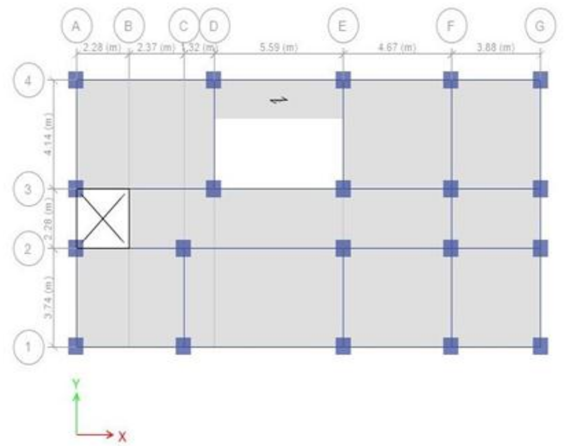


Fig. 3 plan view

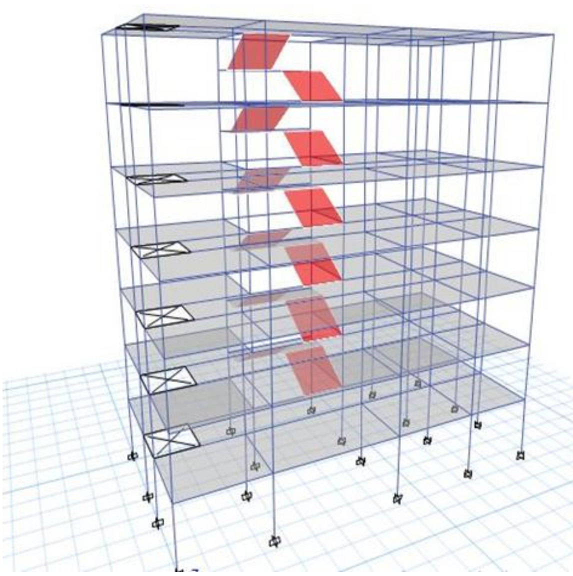


Fig.4 3D view

6.2 MATERIALS AND PROPERTIES OF THE STRUCTURE:

Material	Concrete M30
Steel	FE415
Beam size	250*400mm
Plinth beam	230*230mm
Column sizes	Ground storey: 650*650mm Other storeys: 530*530mm
Slab thickness	200mm
Height of each storey	3m
Dead loads	Slab:1.12 kn/m^2 Beam(inner walls):3.5 kn/m^2 Beam(outer walls):4 kn/m^2
Live loads	Slab:10 kn/m^2
Load combinations	1.5(Dead load + Live load). 1.2(Dead load + Live load). 1.5(Dead + Live + Blast loads).

6.3 CALCULATION OF BLAST LOADS:

Assume a source point from where the blast occurs which is taken as (0, 1.5, 0) from the center of the building

Using two point formula the distance between source and the target is calculated which is as follows.

$X=\sqrt{(x_2-x_1)^2+ (y_2-y_1)^2+ (z_2-z_1)^2}$

Table-3 Distance between source and target for 30m

SLAB	COORDINATE POINTS			DISTANCE BETWEEN SOURCE AND TARGET
1	30	1.5	0	30
	30	1.5	3.74	30.23
	30	1.5	2.28	30.08
	30	1.5	4.14	30.24
2	30	4.5	0	30.14
	30	4.5	3.74	30.38
	30	4.5	2.28	30.23
	30	4.5	4.14	30.43
3	30	7.5	0	30.59
	30	7.5	3.74	30.82
	30	7.5	2.28	30.67
	30	7.5	4.14	30.87
4	30	10.5	0	31.32
	30	10.5	3.74	31.54
	30	10.5	2.28	31.42
	30	10.5	4.14	31.57
5	30	13.5	0	32.31
	30	13.5	3.74	32.52
	30	13.5	2.28	32.39
	30	13.5	4.14	32.57
6	30	16.5	0	33.54
	30	16.5	3.74	33.74
	30	16.5	2.28	33.61
	30	16.5	4.14	33.79
7	30	19.5	0	34.98
	30	19.5	3.74	35.18
	30	19.5	2.28	35.08
	30	19.5	4.14	35.22

Using the above distances scaled distances are calculated and peak reflected pressures are calculated from table-1 of IS 4991:1968.

Here, the blast loads are calculated for the front face of the building

Since, most severe loadings on any face of the structure is produced when the structure is oriented with face normal to the direction of propagation of the shock front. However, as the orientation for any explosion cannot be known before. Hence, every face of the structure is considered to be a front face.

Table-4 Blast pressures for 100kg TNT

SLAB	SCALED DISTANCE (x) m	Pro (KN/m2)	AREA (m2)	FORCE (KN)	Td (milli seconds)
1	64.6	79.42	4.3	341	13.14
	65.12	78.44	6.9	541	13.18
	64.8	87.24	9.5	829	13.16
	65.15	78.44	6.17	484	13.21
2	64.93	78.44	4.3	337	13.18
	65.45	77.46	6.9	534	13.26
	65.12	78.44	9.5	745	13.21
	65.55	76.68	6.17	473	13.27
3	65.9	76.48	4.3	328	13.33
	66.39	75.5	6.9	521	13.37
	66.07	75.39	9.5	716	13.35
	66.5	74.68	6.17	460	13.38
4	67.47	72.56	4.3	312	13.46
	67.95	71.58	6.9	494	13.49
	67.64	72.82	9.5	692	13.46
	67.88	72.83	6.17	447	13.48
5	69.6	70.6	4.3	303	13.58
	70.06	69.62	6.9	480	13.57
	69.78	69.32	9.5	658	13.57
	70.16	38.7	6.17	424	13.57
6	72.25	65.7	4.3	282	14.2
	72.69	64.71	6.9	446	13.95
	72.41	65.03	9.5	618	13.98
	72.49	64.4	6.17	397	13.96
7	75.36	60.79	4.3	261	14.31
	75.79	59.81	6.9	412	14.39
	75.57	60.05	9.5	570	14.35
	75.87	59.65	6.17	368	14.4

The blast loads are applied at the joints of the structure. Application of blast load caused the failure of Hence, the size of the beam and columns are revised and the structure is redesigned. The revised sizes are as follows.

SLAB	SCALED DISTANCE (x) m	Pro (KN/m2)	AREA (m2)	FORCE (KN)	Td (milli seconds)
1	83.33	52	4.3	224	12.04
	83.97	52	6.9	359	11.76
	83.55	52	9.5	494	11.76
	84	52	6.17	321	11.77
2	83.72	52	4.3	224	11.77
	84.38	51	6.9	352	11.78
	83.97	52	9.5	494	11.76
	84.52	51	6.17	315	11.79
3	84.97	51	4.3	219	11.8
	85.61	50	6.9	345	11.82
	85.19	50	9.5	475	11.81
	85.75	50	6.17	308	11.83
4	87	49	4.3	211	11.87
	87.61	48	6.9	331	11.96
	87.27	48	9.5	456	11.91
	87.69	48	6.17	296	11.97
5	89.75	46	4.3	198	12.25
	90.33	45	6.9	310	12.33
	89.97	46	9.5	437	12.28
	90.47	45	6.17	278	12.36
6	93.16	42	4.3	181	12.78
	93.72	41	6.9	283	12.82
	93.36	42	9.5	399	12.79
	93.86	41	6.17	253	12.83
7	97.16	39	4.3	168	13.13
	97.72	39	6.9	269	13.19
	97.44	39	9.5	370	13.16
	97.83	39	6.17	241	13.2

Beam sizes:
Plinth beam: 450*650mm
Others: 500*650mm
Column sizes:
Ground and 1st storey: 750*750mm
Other storeys: 650*650mm

7. ANALYSIS AND RESULTS

The structure is considered as SDOF and Nonlinear dynamic time history analysis was done with a step size of 100 and output time as 0.05sec.
The structure is also analyzed with shear walls placing at different positions and compared

7.1 ANALYSIS WITHOUT SHEAR WALLS:

For 100kg TNT:
The maximum displacement is 0.94mm for 0.05sec at top storey.

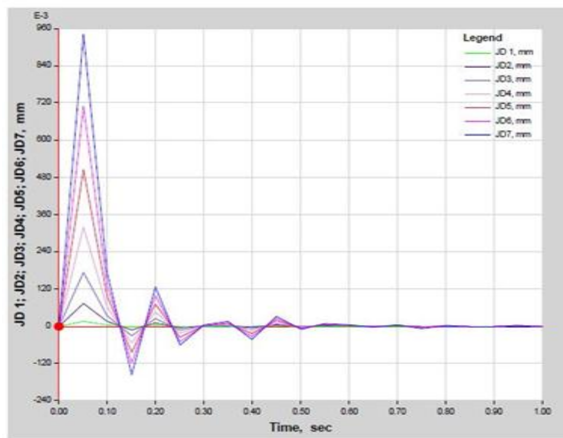


Fig.5 Time history displacements plots for 100kg TNT

The story force is 12915.6KN at ground and 2183.92KN at top storey.

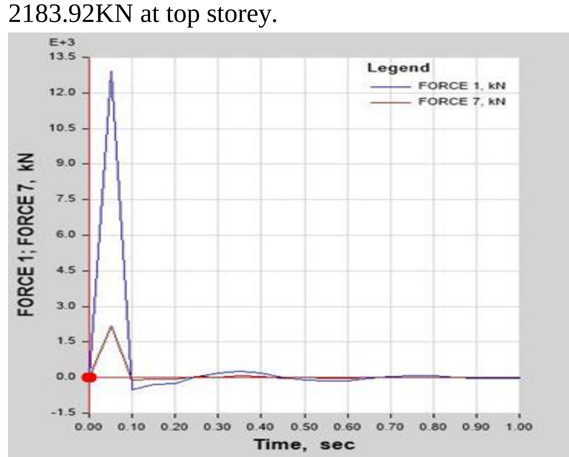


Fig.6 Time history storey forces for 100kg TNT

This graph shows joint displacements for different storey levels upto a time of 1 sec which is least at storey 1 and highest at storey 7 and also as the time increases the displacements are decreased.

The above graph shows storey forces for storey 1 and 7 with storey 1 having the highest peak and lowest peak for storey 7.It can be understood that the blast wave decreases as it propagates from bottom to top storeys.

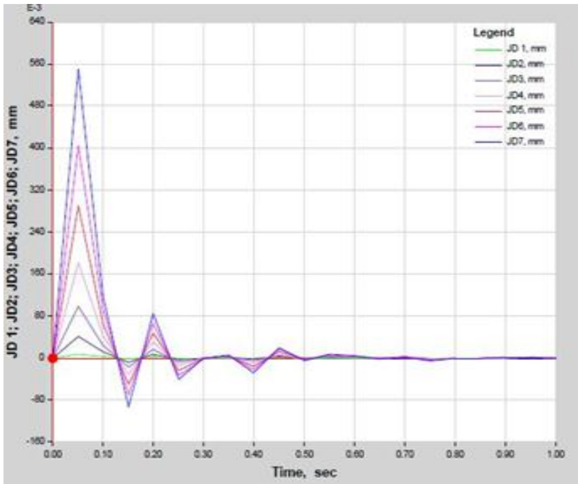


Fig.7 Time history displacement plot for 50kg TNT

For 50kg TNT:

The maximum displacement is 0.550mm for 0.05sec at top storey.

The storey forces are 13447.38KN at ground and 2283.57KN at top storey for 0.05sec.

Fig.8 Time history storey forces for 50kg TNT

This graph shows joint displacements for different storey levels up to a time of 1 sec which is least at storey 1 and highest at storey 7 and also as the time increases the displacement peaks are decreased and when compared to 100 kg TNT the blast wave remains for very short time.

The above graph shows storey forces for storey 1 and 7 with storey 1 having the highest peak and lowest peak for storey 7.It can be understood that the blast wave decreases as it propagates from bottom to top storeys. When compared to 100 kg TNT storey forces are more in this case.

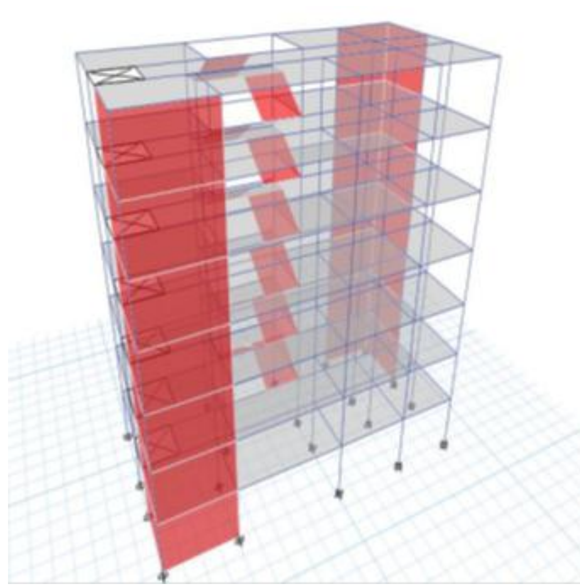
7.2 ANALYSIS WITH SHEAR WALLS:

In this paper analysis of the Structure is studied under three

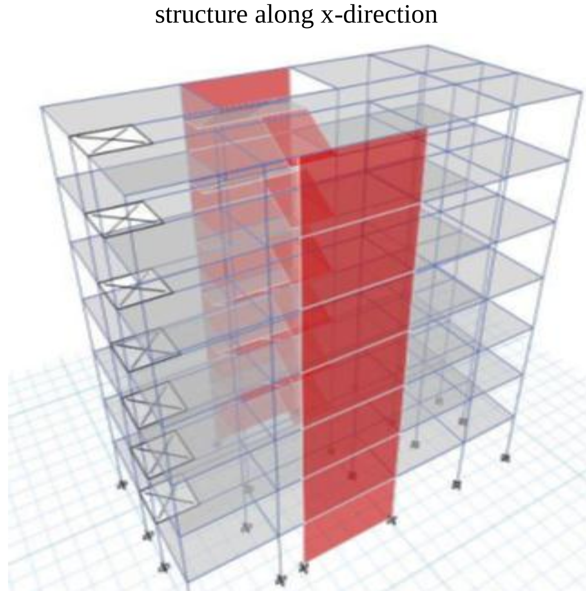
Different positions of shear walls.

Thickness of the shear wall is taken as 230mm.

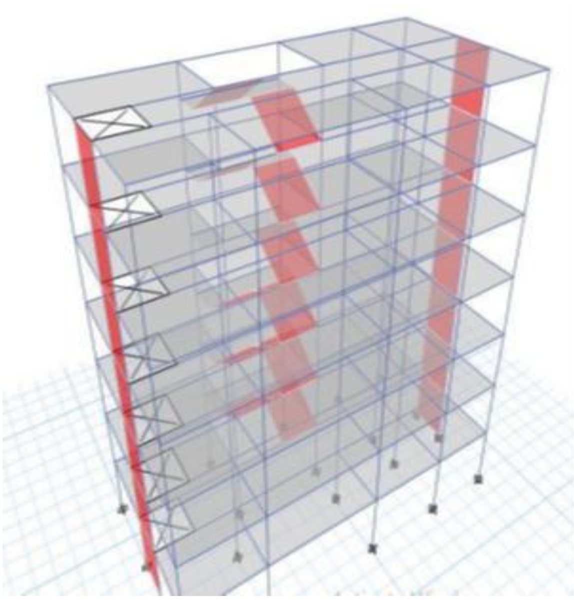
Case (a): Shear walls placed diagonally at the corners of the structure



Case (b): Shear walls placed at opposite sides of the structure along x-direction



Case (c): Shear walls placed at opposite sides of the structure along y-direction



For 100kg TNT:

Case (a): The maximum displacement is 0.631mm at top storey for 0.05sec.

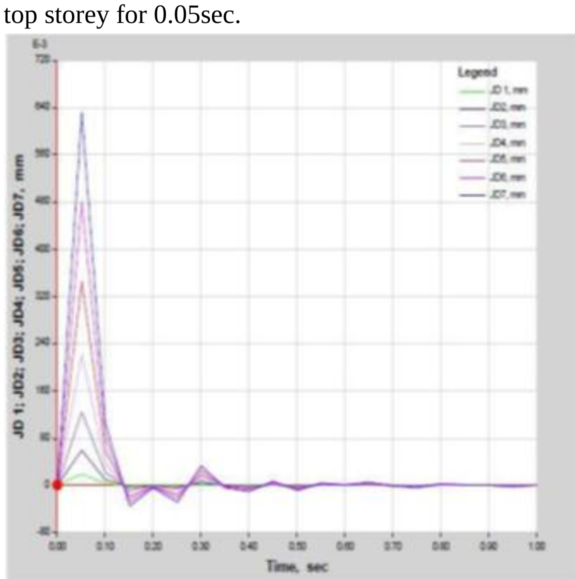


Fig.9 Time history displacement plot with Shear wall for 100kg TNT

The above graph shows joint displacements for different storey levels up to a time of 1sec when shear walls are placed diagonally at the corners of the structure which is least at 1st storey and highest at storey 7.

Case (b): The maximum displacement is 4.017mm at top storey for 0.05sec

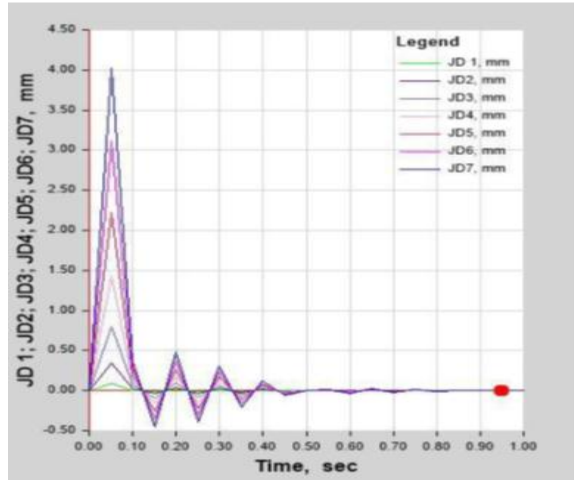


Fig.10 Time history displacement plot with Shear wall for 100 kg TNT

The above graph shows joint displacements for different storey levels up to a time of 1 sec when shear walls are placed along x-direction of the structure which is least at 1st storey and highest at storey 7.when compared case(a) this shows displacement peak of high value.

Case (c): The maximum displacement in this case is 0.576mm at top storey for 0.05 sec

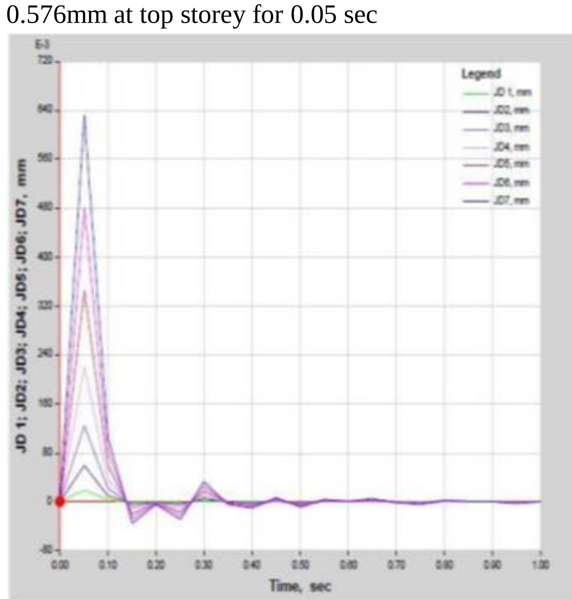


Fig.11 Time history displacement plot with shear wall for 100kg TNT

This graph shows joint displacements for different storey levels up to a time of 1 sec when shear walls are placed along y- direction of the structure which is least at 1st storey and highest at storey7.when compared case(a) and case(b) this shows displacement peak of less value.

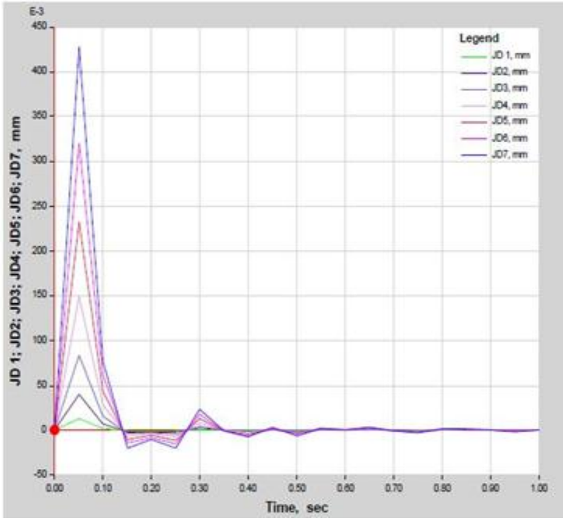


Fig.12 Time history displacement plot with Shear walls for 50kg TNT

Case (a): The maximum displacement is 0.428mm at top storey for 0.05sec.

The above graph shows joint displacements for different storey levels up to a time of 1 sec when shear walls are placed diagonally at the corners of the structure which is least at 1st storey and highest at storey 7.

Case (b): The maximum displacement is 2.593mm at top storey for 0.05sec.

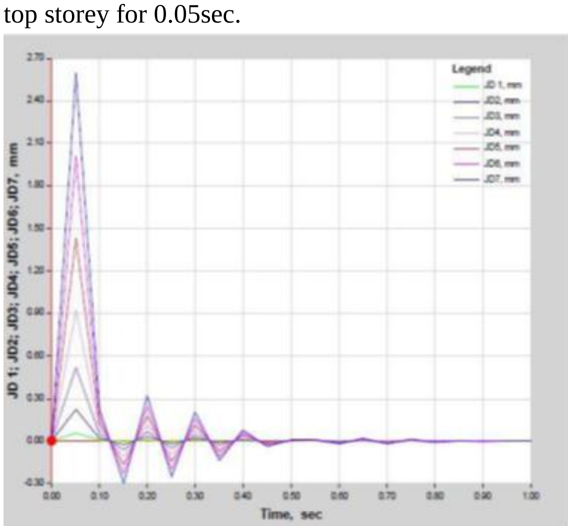


Fig.13 Time history displacement plot with shear walls for 50kg TNT

The above graph shows joint displacements for different storey levels up to a time of 1 sec when shear walls are placed along x-direction of the structure which is least at 1st storey and highest at storey 7.when compared case (a).

Case (c): The maximum displacement is 0.308mm at top storey for 0.05sec.

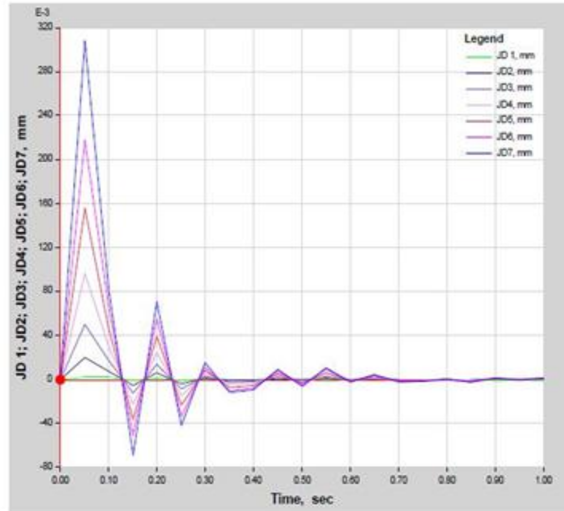


Fig.14 Time history displacement plot with Shear walls for 50kg TNT

This graph shows joint displacements for different storey levels up to a time of 1 sec when shear walls are placed along y-direction of the structure which is least at 1st storey and highest at storey7.when compared case(a) and case(b) this shows displacement peak of less value.

7. CONCLUSION

From time history analysis it is observed that displacements decreases with decrease in the storey levels and storey forces are more at bottom level which decreases with increase in storey height.

By placing shear walls small amount of displacement and forces have been reduced.

For the given plan with 50kg and 100kg TNT at 30m the best position of placing shear wall is along the y-direction of the structure.

It has also been observed that as the charge weight increases the impact on the structure also increases.

Increasing the size of the members also showed significant effect on the structure in resisting blast loads.

Hence, from above observations it can be concluded that by providing moment resisting frames such as shear walls and maintaining appropriate standoff distances maximum damage to the structure can be avoided and also gives time for the occupants to escape from the building.

REFERENCES

[1] Edward, Eskew and Shinae, “Impact and analysis for buildings under terrorist attacks”, 2012.
[2] T.Ngo, “Blast loading and blast effects on structures”, EJSE special issue, 2007.
[3] IS 4991-1968 Criteria for blast resistant design of structures for explosions above ground.
[4] IS 456-2000 Criteria for the design of concrete structures.
[5] FEMA-426, Reference manual to mitigate potential terrorist attacks against buildings.
[6] Mario Paz, “Structural dynamics theory and computation”, S.Chand publications