Behaviour of Conventional and Composite Structure under Blast Loading

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Abstract: *Since last century considerable attention has been diverted towards on the behaviour of engineering structures under blast or impact loading. Terrorists group use explosives around the world that target civilian buildings and other structures has become a major threat to the harmony of life. An explosion not only damages the structural frame of the building but also results in collapsing of walls, flying debris, breaking glasses, thus threatening human life. Due to such threats, now a day's efforts are made to develop methods for analysis and design of high importance buildings to resist blast loads. Generally, the harm from such an explosion are not only related to instant fatalities because of the direct emission of energy, but due to the failure of structural capacity of the building that might occur and could result in extensive life loss. This Present Study includes analysis of two 10 storied, one RCC and other Composite, using Time History analysis. The blast load was analytically determined as a pressure-time history and numerical model of the structure was created in ETABS 2016. The response in terms of various dynamic parameters and the performance of the sample building is studied. Response of blast excited building is studied and reviewed for 0.1 Tonnes and 0.2 Tonnes of TNT placed on ground at 10 m, 21 m, and 30 m. The review mainly emphases on total deflection and performance level of building under blast loads. The blast load is calculated IS 4991-1968 criteria for blast resistant design of structures for above ground explosions. The analysis of either of structure subjected to blast loads requires a peak deflections, drift, and accelerations, is calculated, compared and the RCC structure performed better than the Composite Structure.*

Keywords: *blast load, composite RCC structure, time history analysis, numerical modelling, storey displacement, inter-storey drift, storey acceleration.*

I. INTRODUCTION

Structures designed to resist blast loads are subjected to completely different type of load than that considered in conventional design. In the past decades, a structure subjected to blast load gained importance due to accidental events or natural events. However, in blast phenomenon, the peak intensity lasts for a very small duration only. Thus, there is a need for doing the analysis of performance of the building subjected to blast loading. The blast load can be analytically determined as a pressure-time history and the analysis of structure resistant to blast can be achieved. In a composite structure both the steel and concrete would resist the external loading by interacting together by bond and friction. Supplementary reinforcement in the concrete encasement prevents excessive spalling of concrete both under normal load and fire conditions. Thus, the performance of composite structure should be evaluated when it is subjected to the same condition as a RCC structure.

Figure 2 shows the idealised profile of the pressure in relation to time for the case of a free-air blast wave, which reaches a point at a certain distance from the detonation. 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.

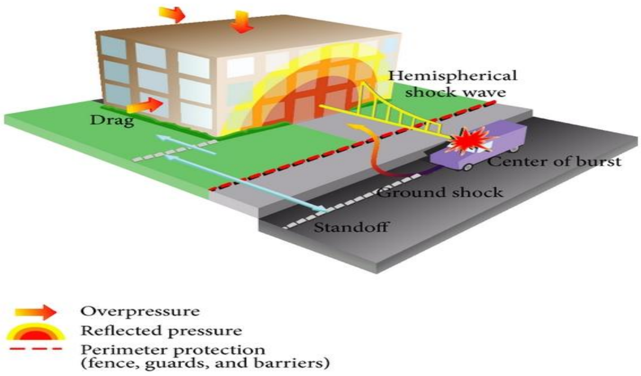


Fig. 1 Bl**ast load on Structure** [4]

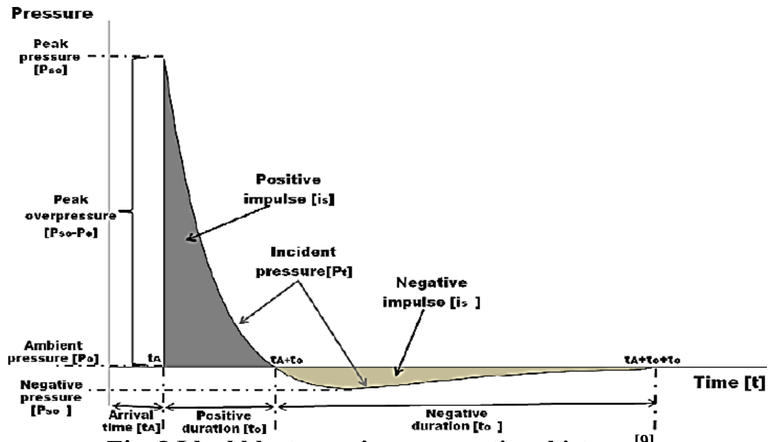


Fig. 2 **Ideal blast wave's pressure time history [9]**

II. LITERATURE REVIEW

Khatavakar *et al.* (2016) found out the importance of standoff distance (distance from the point of explosion) by subjecting two high-rise structures (Closed Structure and Open RC frame Structure) to blast overpressure at varying distances. The minimum distance at which the structure is safe against the blast force is found in both the structural cases. The critical distance or the minimum distance below which the structure is damaged severely is 0.070 km for Closed Structure and 0.090 km for RC frame Structure.

Chiranjeevi *et al.* (2016) has done a study on preventing failure of structures from blast loading and familiarize it with design methods followed as per UFC guidelines. Analysis is carried out for different grades of concrete and results are compared and analysed. Progressive collapse is also checked by providing plastic hinges in the structure as per FEMA 356 provisions using as per UFC guidelines.

Williams *et al.* (2016) analysed the response of a One-Storey One-Bay Steel Frame to Blast. They compared the performances of a seismically designed SDOF frame structure at blast loads at various standoff distances. The method put forward in this paper is useful at the preliminary design stage, as results are accurate according to the blast-resistant design procedures currently in use. Damage of buildings due to external wall damage, that is, glass facades, and so forth was not considered in this study.

Jamakhandi *et al*. (2015), evaluated performance of different shape of building under explosion. Blast load analysis was carried out by performing a time history analysis. The response parameters were observed in terms of Displacement vs the height of building. And Storey drift with respect to stand-off distance.

Hajira *et al*. (2015) compared the seismic behavior of two types of multi stored framed structure consisting of Steel beam, RC Slab & RC Column and Steel beam, RC Slab & Concrete encased steel (CES) Composite column. Both the composite and conventional buildings/structures which are comparatively studied, behave identically for the parameters considered, but Storey drifts and overturning moments are higher that is 80% and 85% in the case of composite building. These results and comparative study observations lead to a conclusion that for low rise buildings composite column design is not suitable.

Jirage *et al*. (2015) analysed a RCC and a composite building models using Equivalent Static Method and Response Spectrum Method for Seismic Analysis. Different parameters such as deflection, story drift, base shear and time period are studied for the models. The displacement of Composite structure is more as compare with RCC. Deflection is within permissible limit. Composite structure is more economical than the RCC Structure. Time required for construction of composite structure is less as compared with RCC structure because no form work is required.

III. RESEARCH METHODOLOGY

In the present study, two 10 storied RCC building and Composite buildings are subjected to a blast loading modelled as a time history function. The parameters of blast loads were calculated as per IS 4991: 1968 and analysis was done. The performance of the structure was evaluated in terms of maximum displacements, inter-storey drifts and total storey accelerations. The blast was set-off at ground level, so the intensity of blast was not considered in above stories, i.e. above 3rd story level, since it is negligible.

Input data

The study is carried out on the same building plan for RCC and composite construction with keeping the cross- sectional area of the members similar for both the structures.

Table 3.1: Common Input Data of 10 storied RCC Building and Composite Building

1	Building Type	RCC & Composite
3	Building Dimension	24m × 12 m.
4	No of Bays in X Direction, Spacing	4 Bays @ 6 m c/c
5	No of Bays in Y Direction, Spacing	3 Bays @ 4 m c/c
6	No of Storey	10 Nos.
8	Floor to Floor height	3 mt.
9	Size of RCC Columns	500 mm X 500 mm
10	Size of RCC Beams	300 mm X 600 mm
11	Size of Composite Column	600 mm X 400 mm (ISWB 450- Encased)
12	Size of Steel Beam	ISWB 400
13	Thickness of Slab	200 mm

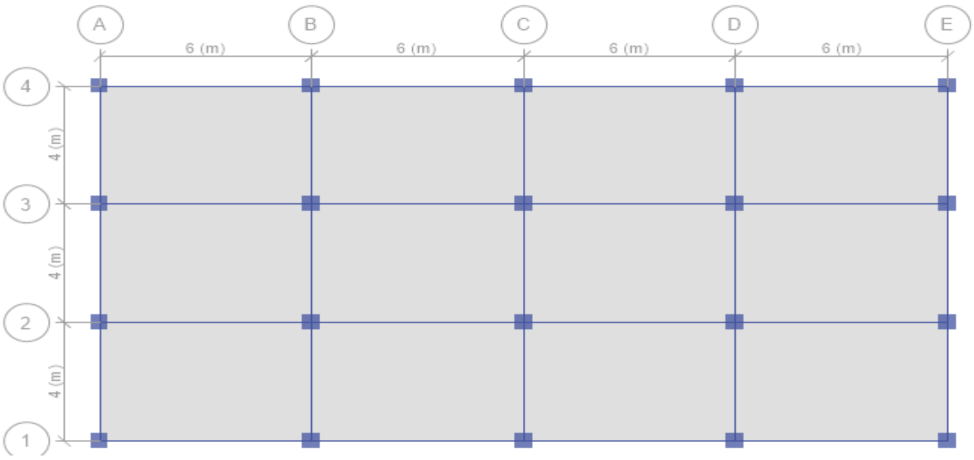


Fig. 3.1 Plan of the Building

Table 3.2: Loading details of 10 storied RCC Building and Composite Building

1	Dead Load		Self-Weight of all Members	
2	Live Load		5 kN/m^2 on all Slabs	
3	Super Imposed Dead Load		= Density of Bricks X Wall thickness X Wall Height = 13.5 kN/m	
4	Blast load	Loading Pattern	Intensity	Stand- off distance
		Pattern 01	0.1 Tonnes TNT	10 m
		Pattern 02	0.2 Tonnes TNT	10 m
		Pattern 03	0.1 Tonnes TNT	21 m
		Pattern 04	0.2 Tonnes TNT	21 m
		Pattern 05	0.1 Tonnes TNT	30 m
		Pattern 06	0.2 Tonnes TNT	30 m

IV. ANALYSIS

Modelling of the Structure is carried out on ETABS 2016 16.0.2 a Product of Computer and Structure Inc. The input data used for modelling is as stated. ETABS was selected due to the reason that Blast analysis can be carried out by performing a time history analysis in which the blast loading is applied.

Table 3.3: Blast load parameters obtained from IS 4991: 1968 for 0.1 tonnes TNT

Parameters	Symbol	For Standoff Distances (0.1 Tonnes TNT)		
		10 m	21 m	30 m
Scaled Distance (m)	Z	21.54	45.22	64.63
Peak side overpressure ratio	p_{so}/p_a	3.138	0.66	0.35
Positive Phase Duration (milliseconds)	t_d	9.67	31.3	28.32
Duration of equivalent triangular pulse (millisecond)	t_o	16.78	21.6	37.70
Dynamic pressure ratio (kg/cm²)	q_0/p_a	2.44	0.139	0.042
Peak reflected Overpressure ratio (kg/cm²)	p_{ro}/p_a	12.13	1.476	0.806

Table 3.4: Blast load parameters obtained from IS 4991: 1968 for 0.2 tonnes TNT

Parameters	Symbol	For Standoff Distances (0.2 Tonnes TNT)		
		10 m	21 m	30 m
Scaled Distance (m)	Z	17.09	35.90	51.29
Peak side overpressure ratio	p_{so}/p_a	5.91	1.00	0.525
Positive Phase Duration (milliseconds)	t_d	6.63	17.30	23.79
Duration of equivalent triangular pulse (millisecond)	t_o	10.54	26.65	33.61
Dynamic pressure ratio (kg/cm²)	q_0/p_a	6.86	0.316	0.091
Peak reflected Overpressure ratio (kg/cm²)	p_{ro}/p_a	28.29	2.77	1.26

V. RESULTS AND DISCUSSION

The blast load parameters are computed as per IS: 4991-1968 and pressure time history method is carried out. The front face pressure is applied as a uniformly distributed load to the beams & columns by multiplying the width of the beam or column with the blast pressures. The results of time history analysis are found out in terms of storey displacement, storey acceleration and total storey drift.

Maximum Storey Displacement

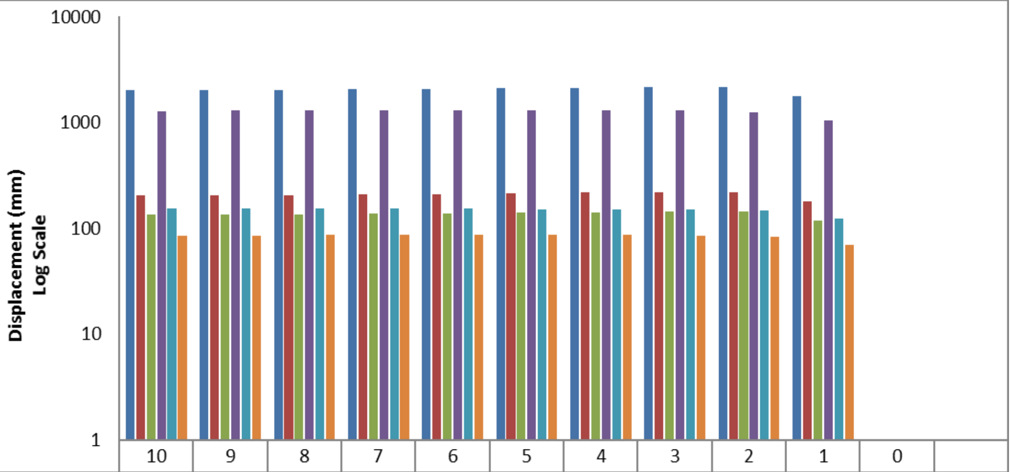
Maximum Displacement was calculated to be 1304.46 mm at the fourth level of RCC Structure and 2179.77 mm at the third level for Composite Structure, under Load Combination 03 and 01 respectively. Maximum Displacement was observed at those combinations because the charge was detonated at 10 m in either of the cases. Figure 4.1 shows the graph of Maximum Displacement of Stories for RCC & Composite Structure under combination of blast loadings.

Inter- Storey Drift

The maximum inter-story drift was observed at the first level of RCC Structure and Composite Structure, under Load Combination 03 and 01 respectively. Maximum Drift was calculated to be 0.506 at the first level of RCC Structure and 0.300 for Composite Structure, under Load Combination 03 and 01 respectively. The graph of inter-storey drift between each storey after the RCC and Composite Structures were subjected to blast loading, with varying stand-off distances, of 0.1 tonnes TNT charge is shown in Figure: 4.2.

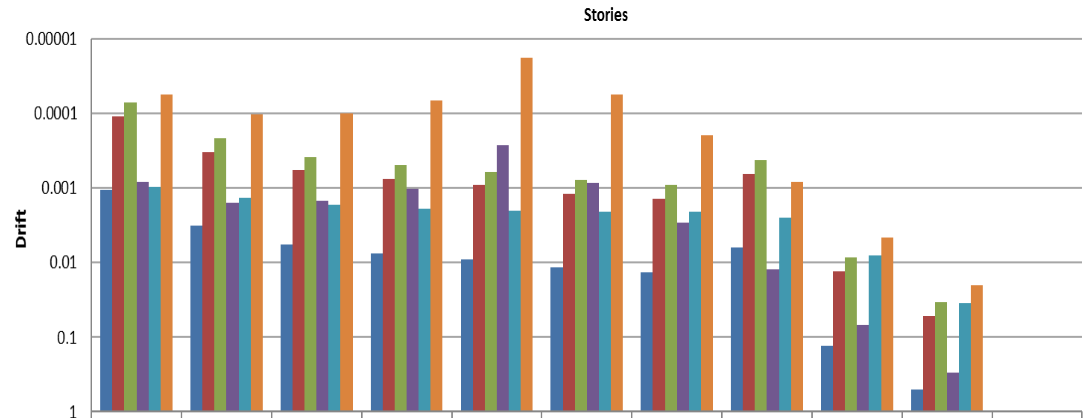
Total Storey Acceleration

Figure 4.3 shows the amount of acceleration generated in each storey for the RCC and Composite Structures subjected to blast loading subjected to different stand-off distances under 0.1 tonnes TNT charge. Maximum Storey acceleration was 2898.7 mm/sec2 at the fourth level of RCC Structure and 5085.1 mm/sec2 at the first level for Composite Structure, under Load Combination 03 and 01 respectively. Maximum Storey acceleration showed a gradual rise until the fourth level then a similar fall in case of RCC structure; whereas, in case of composite structure it was steeper.



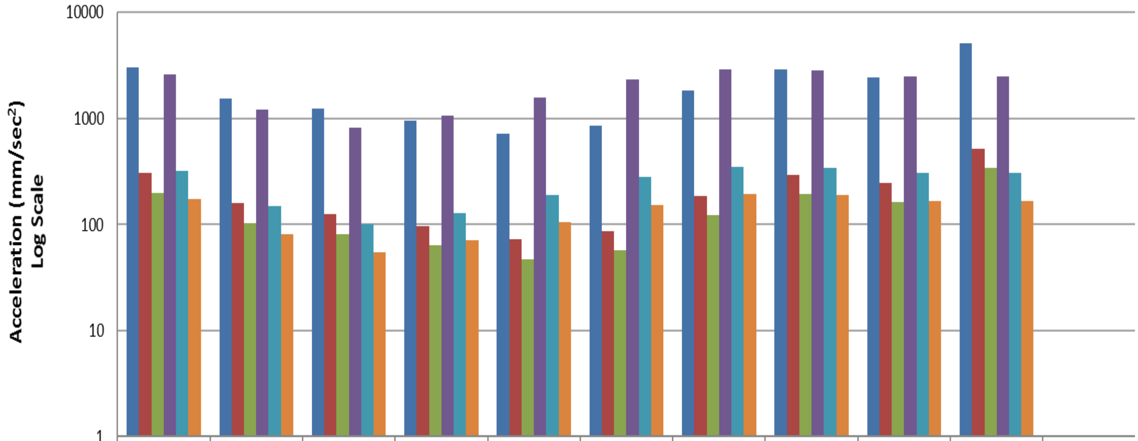
	10	9	8	7	6	5	4	3	2	1	0
Composite- Pattern 01	2024.87	2028.08	2037.74	2054.73	2077.01	2103.98	2139.1	2179.77	2160.94	1773.25	0
Composite-Pattern 03	205.583	205.908	206.889	208.614	210.877	213.615	217.18	221.309	219.398	180.036	0
Composite-Pattern 05	134.715	134.928	135.571	136.702	138.184	139.978	142.315	145.02	143.768	117.975	0
RCC- Pattern 01	1289.07	1291.55	1296.21	1300.64	1303.66	1304.46	1301.92	1293.14	1256.25	1051.75	0
RCC- Pattern 03	155.745	154.511	153.852	153.37	152.931	152.486	152.007	151.222	147.465	123.83	0
RCC- Pattern 05	85.645	85.81	86.12	86.414	86.615	86.668	86.499	85.916	83.465	69.878	0

Fig. 4.1 Total Storey Displacements



	10	9	8	7	6	5	4	3	2	1	0
Composite- Pattern 01	0.001068	0.003222	0.005664	0.007427	0.00899	0.011707	0.013556	0.006276	0.12923	0.506644	0
Composite-Pattern 03	0.000108	0.000327	0.000575	0.000754	0.000913	0.001189	0.001376	0.000637	0.013121	0.051439	0
Composite-Pattern 05	7.10E-05	0.000214	0.000377	0.000494	0.000598	0.000779	0.000902	0.000418	0.008598	0.033707	0
RCC- Pattern 01	0.000826	0.001555	0.001478	0.001007	0.000264	0.000845	0.002926	0.012299	0.068167	0.300499	0
RCC- Pattern 03	0.000947	0.001358	0.001669	0.001873	0.001991	0.002044	0.002086	0.002501	0.008044	0.03538	0
RCC- Pattern 05	5.50E-05	0.000103	9.80E-05	6.70E-05	1.80E-05	5.60E-05	0.000194	0.000817	0.004529	0.019965	0

Fig. 4.2 Inter- Storey Drift



	10	9	8	7	6	5	4	3	2	1	0
Composite- Pattern 01	3005.77	1552.32	1224.27	950.86	712.63	854.02	1843.44	2898.83	2447.92	5085.01	0
Composite-Pattern 03	305.17	157.61	124.3	96.54	72.35	86.71	187.16	294.31	248.53	516.27	0
Composite-Pattern 05	199.97	103.28	81.45	63.26	47.41	56.82	122.64	192.86	162.86	338.31	0
RCC- Pattern 01	2623.88	1223.34	825.55	1058.03	1568.01	2306.83	2898.7	2836.54	2497.03	2497.29	0
RCC- Pattern 03	319.25	148.84	100.44	128.73	190.78	280.67	352.68	345.12	303.81	303.84	0
RCC- Pattern 05	174.33	81.28	54.85	70.3	104.18	153.27	192.59	188.46	165.9	165.92	0

Stories

Fig. 4.3 Total Storey Acceleration

VI. CONCLUSION

1. It has been observed that the dynamic response of 10 storied RCC structure & Composite structure is discussed under two different charge weights at same stand-off distances under blast loading.From the above observation reflected blast wave pressure is more in the case of bottom floors, low in top floors for same charge weights at a different level.
2. From the above observation reflected blast wave pressure is more in the case of bottom floors, low in top floors for same charge weights at a different level. Maximum deformations have been observed when the blast was detonated at the distance of 10 m when compared with others.

- By using Composite Members instead of RCC and keeping all the parameters of the structure same, the following points were observed:
- Maximum Displacement showed an increase of maximum of 67.10 %, 42.10 % and 67.65 % for the blast charges of 0.1 tonnes TNT at varying stand-off distance of 10 m, 21 m and 30 m respectively.
- Ground storey is worst affected in terms of both strength and serviceability since the blast is carried out at ground level. Inter-story drift showed an increase of maximum of 40.68 %, 31.22 % and 40.76 % for the blast charges of 0.1 tonnes TNT at varying stand-off distance of 10 m, 21 m and 30 m respectively.

3. Maximum Displacement showed an increase of maximum of 50.88 %, 41.14 % and 50.95 % for the blast charges of 0.1 tonnes TNT at varying stand-off distance of 10 m, 21 m and 30 m respectively. The maximum values of acceleration and velocity at nodes of 4^{th} storey for RCC structure and 1^{st} story for composite structure depicts that highest discomfort will be experienced by inhabitants on the same storey during blast.
4. The blast pressure is least when the point of detonation is far away from the building, at 30m from the front face of the building, in this case. The pressure decreases exponentially as the stand-off distance increases. The pressure is inversely proportional to detonation point.
5. Though by using Composite structure in place of RCC the overall weight of the structure is reduced, and the pace is increased in construction stage, there is increase in the displacements, inter-story drift of the structure, which makes it unsuitable to withstand the blast loadings. RCC frame has the lowest values of deformation because of its high stiffness.

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