ANALYSIS OF BLAST RESISTANT STRUCTURE

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Abstract - *Bomb explosion near a building can cause disastrous damage to the building externally and internally. This can cause minor, moderate or major damage to the building. The main aim of this study is to do a comparative analysis of building models and know the response when subjected to blast loads using ETABS software. In this study a 12-storey building is subjected to 100kg and 200kg TNT charge weight with stand of distance 20m and 40m. Blast parameters are calculated using IS 4991-1968.Further four models are considered by implementing different structural systems and response of the models in terms of storey displacement and storey drift is considered to know the model with the structural element that helps resist the effect of blast.*

Key Words: *Analysis, ETABS, Blast, Storey Displacement, Storey Drift*

1. INTRODUCTION

Structures, majorly that have higher chances of being target of terrorist attacks should be safe from the blast effects. It is important to study accordingly into this area to reduce the losses caused due to the blast effects on the buildings. The dynamic replica of the structure to blast loading is complicated to analyse because of the non-linear action of material. Blast explosions result in voluminous dynamic loads, more complex than the original design loads, so for analysis and design of blast loading detailed knowledge is required of blast and its phenomena. Due to increase in technology, the buildings mostly in large cities are concentrated much on the comfort of living and the safety against earthquake and wind loads but not concentrated much on the blast loads. As explosions are becoming common in metropolitan cities consideration of blast loads on tall buildings especially public and commercial buildings is necessary. In blast analysis, one can determine the acceptable damage level that a structure can go through and designed accordingly so that the structure can manage to withstand even under worst conditions. When the explosion occurs, the damage can occur directly or indirectly, externally or internally and so it should be possibly safe in all the ways; prediction, prevention and mitigation of such events are of major concern. This study refers to the analysis of the building under blast load and its impact on the structure in response to storey displacement and storey drift for different models implemented with different structural elements. The models are analysed and compared to know the blast resistant building model to prevent overall collapse of the building in reference to the storey displacement and storey drift.

1.1 Blast Loading Categories:

•Unconfined Explosions:

The explosion that occurs in open air causes a wave that spreads from the source of detonation to the structure without any wave amplification, as the explosion is at a certain distance and height of structure the wave increases due to the reflection of ground before it contacts the structure.

The explosion near the ground is an explosion occurring near or on the ground and the initial pressure is immediately increased as a result of refraction on the ground.

•Confined Explosions:

If the explosion occurs inside the structure, the peak pressures associated with the initial wave fronts are extremely high. They are enhanced by the refraction within the structure. In addition to this, depending on the degree of confinement, high temperatures and the accumulation of gaseous products of chemical reactions in the blast would produce more pressure and increase the load duration within the structure. The combined effects of these pressures can lead to the collapse of the structure, if the structure is not designed to withstand internal pressure. Effect of pressure is different in structures with openings and structures without openings.

1.2 Expected Damage Levels:

•Minor:

- Non-structural failure of building elements such windows, doors.
- Injuries may be expected and deaths are possible but unlikely.

•Moderate:

- Structural damage is confined to a localized area and is usually repairable.
- Structural failure is limited to secondary structural members, such as beams, slabs and non-load bearing walls.

  - Injuries and deaths are expected.

- Major:
  - Loss of primary structural members such as columns.
  - In this case, extensive deaths are expected.
  - Building becomes non repairable.

1.3 Need:

- To resist or survive terrorist attacks.
- To minimize damage to the assets.
- To minimize the loss of lives.
- To subside social panic.
- To protect the historical monuments and important buildings.

1.4 Blast Phenomena:

The term blast is used commonly to describe situation in which rapid release of energy occurs from a chemical, mechanical or nuclear source. Structures designed to resist blast load are subjected to completely different type of load than considered in regular design. Here they are hit with a rapidly moving shock wave which may exert pressure many times greater than those experienced under storms. A blast load is the load applied to a structure or object from a blast wave, which is described by the combination of overpressure that is the rise in pressure above atmospheric pressure due to the shock wave from an air blast, and either impulse or duration that causes catastrophic damage to the building both externally and internally. Blast effect is the damage caused by the force of an explosive blast. When the blast occurs at a location there will be a huge amount of hot gases released which is the compresses the surrounding gases and travels away from the blast source with higher velocity. The distance between the blast source point and the structure is called as the standoff distance. As the blast wave travels away from the blast source the pressure or the intensity of the wave goes on reducing and due to this the effect on the building with higher standoff distance will be less and the time duration required to reach the building is reduced. the blast wave propagation curves depending on the pressure and distance from the explosion or the blast source. A blast wave generated during an explosion spreads through the surrounding air and due to which a shock front or wave is created. This shock wave created surround the entire building subjected to blast pressure. Due to the impulsive load developed by an explosion is highly nonlinear and cause pressure in an extremely short duration, analysis of the reinforced concrete frame structure is difficult. Pressure intensities will be depended upon the charge weight (bomb size) and standoff distances between blast source and impacted structure (target). The factors affecting the blast load are the material type, weight of the explosive, amount of the energy released during the blast, distance between the detonation point and the structure called as standoff distance and intensity of the pressure released.

1.5 General Recommendations for Planning Blast Resistant Buildings:

The IS Code 4991-1968 appendix C gives the general recommendations for planning blast resistant buildings.

- Size of rooms: small size of rooms generally confines the blast damage to a limited area of the structure, because of the screening action of the partition walls.

- Corridors: long narrow corridors should be avoided as they tend to increase the extent of damage along the length of the corridors because of ‘multiple reflections.

- Projections: all slender projections like, parapets and balconies specially those made of brittle materials should be avoided as far as possible.

- Chimneys: masonry chimneys on factory buildings and boiler houses are a potential hazard and should be avoided.

- Roofing and cladding materials: brittle roofing materials, such as tiles and corrugated asbestos sheets are especially prone to blast damage. When corrugated galvanized iron sheets are used for roofing and/or cladding, particular attention should be paid to the fixtures fastening the corrugated galvanized iron sheets to the framework.

- Use of timber and other inflammable materials: these are especially prone to catch fire in a strafing or incendiary attack and should be best avoided in strategic structures where such attacks might be expected.

- Electric wiring: conduit wiring is preferable to open wiring, as in case of large movement of the walls the conduit will give an added protection to the wiring inside and prevent them from getting cut thus preventing fire hazards due to short circuits.

- Glass panes: the most widespread damage due to blast is the breaking of glass panes. The splinters from shattered glass window are dangerous to personnel safety. It is preferable to use non-splintering type glass panes wherever their use cannot be avoided.

- Doors: doors should be designed for the front face load. Wall thicknesses against flying splinters for protection against splinters from bombs with equivalent bare charges exploding at a distance of 15 m, the wall thicknesses given in table 8 will be adequate.

1.6 Blast Load Parameters:

According to the IS Code 4991-1968: Criteria for blast resistant design of structure for explosions above ground use of TNT (Trinitrotoluene) which is a pale yellow, solid organic nitrogen compound used chiefly as an explosive, is considered as a reference for determining the blast parameters for different charge weights and standoff distances. The blast parameters calculated for the study are in the similar way as shown in the example in the IS Code.

Example from IS Code 4991-1968, appendix A for calculation of blast parameters for the rectangular building above ground

Blast parameters due to the detonation of a 0.1 tonne explosive are evaluated on an above ground rectangular structure, 3 m high, 10 m wide and 8 m long, situated at 30 m from ground zero.

a) Characteristics of the Blast:

Scaled distance x = 30/ (0.1)1/3 = 64.65 m

From Table 1 of IS Code assuming pa = 1.00 kg/cm2 and linearly interpolating between 63 m and 66 m for the scaled distance 64.65 m, the pressures are directly obtained:

Pso= 0.35 kg/cm2; Pro = 0.81 kg/cm2; qo= 0.042 kg/cm2

The scaled times to and td obtained from Table 1 of IS Code for scaled distance 64.65 m are multiplied by (0.1)1/3 to get the values of the respective quantities for the actual explosion of 0.1 tonne charge.

to = 37.71 (0.1)1/3 = 17.5 milliseconds; td =28.32 (0.1)1/3 = 13.15 milliseconds

M = 1+ 6 pso / 7pa = 1.14

a = 344 m/s; U = 1.14 * 344 = 392 m/s = 0.392 m/millisecond

b) Pressures on the Building:

Here H = 3 m, B = 10 m, and L = 8 m

Then S = 3 m

tc = 3S/U= 3x3/0.392= 23.0 milliseconds> td

tt = L/U = 8/0.392 = 20.4 milliseconds > td

tr = 4S/U = 4*3/0.392 = 30.6 milliseconds > td

As tr > td no pressure on the back face are considered.

For Front Face:

Pro = 0.81 kg/cm2

For roof and sides:

Cd= -0.4; pso+ Cd*qo = 0.35-0.4 * 0.042 = 0.33 kg/cm2

Here, 0.1 Tonne TNT Explosive is considered for standoff distance 30 m

pa = ambient atmospheric pressure; pso= peak side-on overpressure

pro= peak reflected overpressure; qo = peak dynamic pressure

to = positive phase duration; td = duration of equivalent triangular pulse

M = mach no. = 1+ 6 pso / 7pa

a = velocity of sound in air

U = shock front velocity = M*a

S = H or B/2 whichever is less.

Cd = drag coefficient, considered from table 2 of IS Code.

3. METHODOLOGY

ETABS software is used in this study. A 12-storey structure is considered subjected to 100kg and 200kg charge weight for different standoff distances of 20m and 40 m for each charge weight. Dead load, live load and blast load are considered for the analysis. Four cases are considered corresponding to the charge weights and standoff distances respectively. All the blast parameters are calculated using the IS Code 4991-1968 for the four cases. The peak reflected overpressure obtained for the front and side face of the structure is multiplied with the tributary area of the joint and blast load is calculated. The calculated blast load is applied as the joint load on all the storeys of the structure and analysis is done using software. Response of the structures for four cases in terms of storey displacement and storey drift are observed. For further study, four models are generated; the structure among the four cases that shows maximum displacement and drift is considered as first model and other three models are generated with different structural elements respectively. Now all the four models are analyzed in the software to observe the response of models in terms of storey displacement and storey drift to conclude by analyzing the model that is more resistant to blast load.

- **Cases considered for analysis:**

Case 1: Blast of 100kg explosive with standoff distance of 20m

Case 2: Blast of 100kg explosive with standoff distance of 40m

Case 3: Blast of 200kg explosive with standoff distance of 20m

Case 4: Blast of 200kg explosive with standoff distance of 40m

- **Four different models generated for analysis:**

Model 1 - Normal Building Structure

Model 2- Building Structure with increased column & beam sizes.

Model 3 - Building Structure with addition of shear walls at the corners.

Model 4 - Building Structure with addition of steel bracing at the corners.

4. MODELING AND ANALYSIS

Table -1: Model data

No of grid in x direction	5
No of grid in y direction	4
Spacing of grid in x direction	5
Spacing of grid in y direction	4
No of storey	12
Storey height	3 m
Bottom storey height	3 m
Size of column	400*400 mm
Size of beam	300*300 mm
Thickness of slab	150 mm
Live Load	3 kn/m^2
Brick Masonry external wall	0.230 m
Brick Masonry internal wall	0.115 m

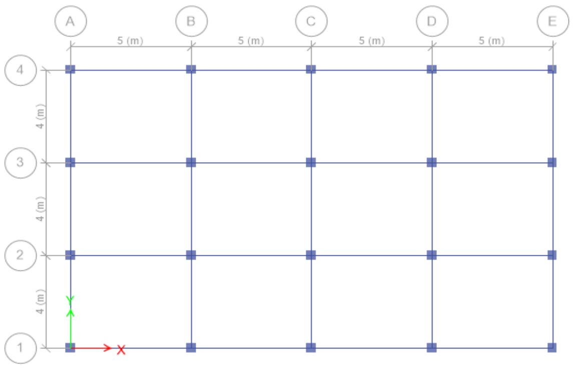

Fig -1: Plan view of building.

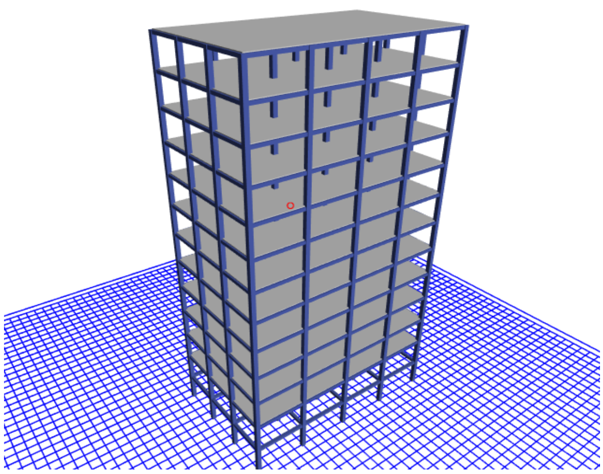

Fig -2: 3D view of building.

Table -2: Blast load calculations

Blast Parameters	Case 1	Case 2	Case 3	Case 4
Blast (kg)	100	100	200	200
Standoff distance (m)	20	40	20	40
Scaled distance (m)	43.08	86.17	34.19	68.39
pa (kg/cm$^{2)}$	1	1	1	1
pso(kg/cm$^{2)}$	0.724	0.232	1.120	0.324
pro(kg/cm$^{2)}$	1.858	0.508	2.981	0.730
qo(kg/cm$^{2)}$	0.170	0.018	0.388	0.035
to(milliseconds)	13.915	19.820	14.99	22.602
td(milliseconds)	9.626	14.940	9.91	17.047
M	1.26	1.095	1.39	1.132
a(m/s)	344	344	344	344
U	0.433	0.376	0.478	0.389
B	12	12	12	12
L	20	20	20	20
S	6	6	6	6
tc	41.57	47.87	37.65	46.27
tt	46.18	53.19	41.84	51.41
tr	55.42	63.82	50.20	61.69
Cd	-0.4	-0.4	-0.4	-0.4
Front Face Pressure	1.858	0.508	2.981	0.730
Side Face Pressure	0.656	0.224	0.964	0.31
Loads on front face joints of the structure x-direction (KN)				
Load on side joints	675	187.5	1087.5	270
Load on edge joints	1350	375	2175	540
Load on centre joints	2700	750	4350	1080
Loads on side face joints of the structure y-direction (KN)				
Load on side joints	540	150	870	216
Load on edge joints	1080	300	1740	432
Load on centre joints	2160	600	3480	864

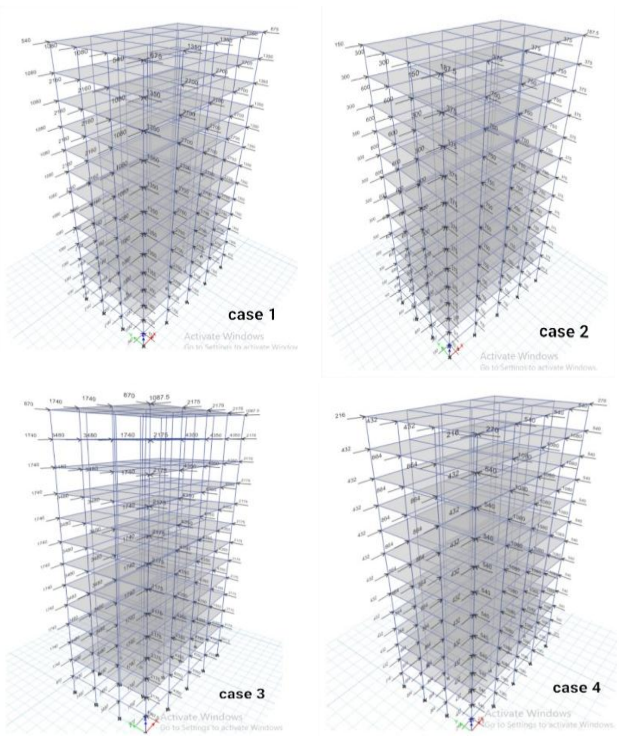

Fig -3: Load application on building for four cases.

Storey	Elevation	Displacement in mm			
		Case 1	Case 2	Case 3	Case 4
Storey 13	39	4938.049	1370.375	7948.052	3082.084
Storey 12	36	4877.462	1353.631	7851.101	3031.572
Storey 11	33	4768.547	1323.354	7675.447	2952.023
Storey 10	30	4602.886	1277.338	7408.562	2839.079
Storey 09	27	4379.227	1215.211	7048.225	2692.185
Storey 08	24	4097.418	1136.932	6594.206	2511.446
Storey 07	21	3757.636	1042.549	6046.786	2297.172
Storey 06	18	3360.148	932.137	5406.397	2049.768
Storey 05	15	2905.265	805.782	4673.536	1769.712
Storey 04	12	2393.153	663.542	3848.548	1457.464
Storey 03	9	1823.708	505.296	2930.721	1112.988
Storey 02	6	1190.831	329.874	1913.287	733.077
Storey 01	3	482.778	133.606	775.096	300.638
Base	0	0	0	0	0

Fig -4: Displacement comparison for four cases

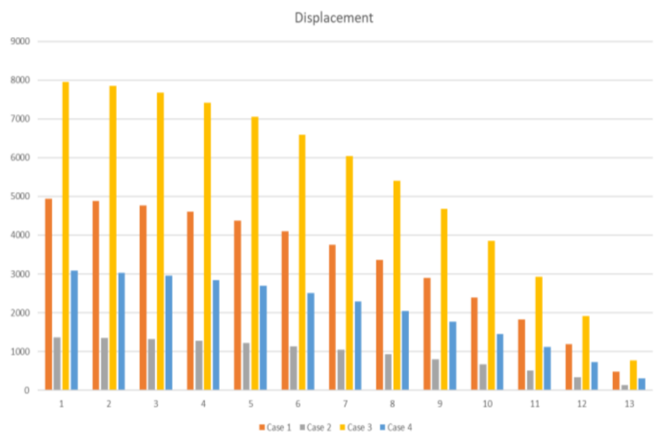

Fig -5: Displacement comparison for four cases

Storey	Elevation	Drift in mm			
		Case 1	Case 2	Case 3	Case 4
Storey 13	39	0.020324	0.005636	0.032752	0.008122
Storey 12	36	0.036361	0.010101	0.058579	0.014545
Storey 11	33	0.055221	0.015339	0.088964	0.022088
Storey 10	30	0.074554	0.020709	0.120113	0.029821
Storey 09	27	0.093936	0.026093	0.15134	0.037574
Storey 08	24	0.113261	0.031461	0.182474	0.045304
Storey 07	21	0.132496	0.036804	0.213464	0.052998
Storey 06	18	0.151629	0.042119	0.244289	0.060651
Storey 05	15	0.170704	0.047417	0.27502	0.068281
Storey 04	12	0.189963	0.052766	0.306046	0.075984
Storey 03	9	0.21158	0.058777	0.340915	0.08464
Storey 02	6	0.24316	0.067481	0.39143	0.097176
Storey 01	3	0.160926	0.044535	0.258365	0.064136
Base 0	0	0	0	0	0

Fig -6: Drift comparison for four cases

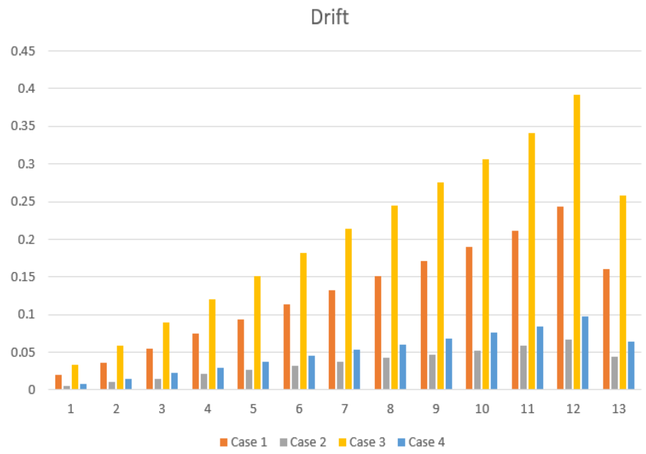

Fig -7: Drift comparison for four cases

Model 1: Among the four cases analyzed the case 3 has the maximum displacement and drift. It shows that for increase in blast load and decrease in standoff distance, displacement and drift increases drastically. For further study case 3 is considered as model 1 and response in terms of storey displacement and storey drift is observed.

Model 2: For creating the model 2, the model 1 is considered and changes are done in terms of columns and beams of the structure for the similar blast load. Column is a structural element that transmits, through compression, the weight of the structure above to the other structural elements below. Beam is a horizontal member spanning an opening and carrying a load that may be a brick or stone wall above the opening. For this model the column and beam sizes are increased. Column size is changed from 400x400 mm to 600x600 mm. Beam size is changed from 300x300 mm to 450x450 mm. The model is then analyzed and response in terms of storey displacement and storey drift is observed.

Model 3: For creating the model 3, the model 1 is considered and changes are done in terms of adding shear wall to the structure for the similar blast load. Shear wall is structural element that is a rigid vertical diaphragm capable of transferring lateral forces from exterior walls, floors and roofs to the ground foundation in a direction parallel to their planes, it resists the forces such as wind, seismic and also blast. For this model shear walls are added at the corners of the structure, the thickness of the shear wall is considered as 150 mm. The model is then analyzed and response in terms of storey displacement and storey drift is observed.

Model 4: For creating the model 4, the model 1 is considered and changes are done in terms of adding bracings to the structure for the similar blast load. Bracings are structural elements that provide stability and resists loads, they consist of devices that clamp parts of structure together in order to strengthen or support it, it resists the forces such as wind, seismic and also blast. For this model bracings are added at the corners of the structure, X-steel bracings, ISWB500 are considered. The model is then analyzed and response in terms of storey displacement and storey drift is observed.

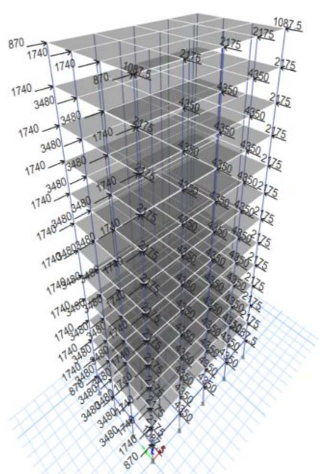

Fig -7: Model 1

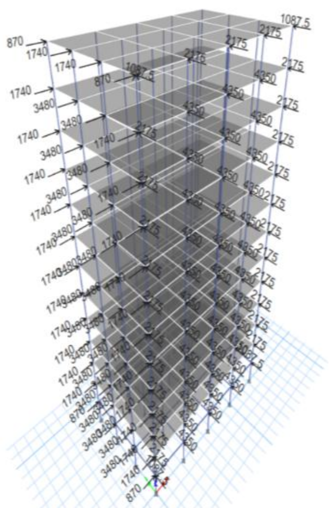

Fig -8: Model 2

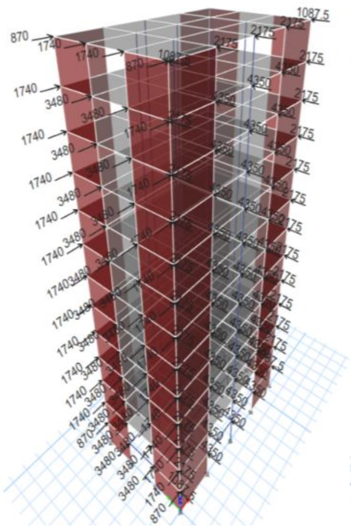

Fig -9: Model 3

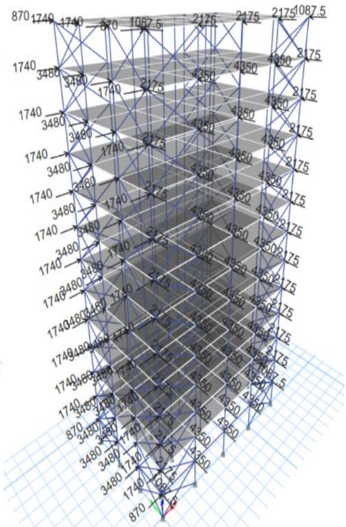

Fig -10: Model 4

5. RESULTS AND DISCUSSION

The aim of blast resistant building study is to prevent the overall collapse of the building and prevent more damage to the building. In spite of the fact that the extent of the explosion and the loads cannot be predicted perfectly or accurately. The most possible actions and considerations will help to find the necessary engineering solutions for it.

In this study the scenario considered are the response for assumed blast on the structure in terms of storey displacement and storey drift.

Storey Displacement: It is the total displacement of the storey with respect to ground.

Storey Drift: It is the lateral displacement of a floor relative to the floor below.

Displacement in mm					
Storey	Elevation	Model 1	Model 2	Model 3	Model 4
Storey 13	39	7948.052	3926.863	1135.376	2030.606
Storey 12	36	7851.101	3870.805	1035.903	1873.904
Storey 11	33	7675.447	3774.044	934.823	1711.435
Storey 10	30	7408.562	3633.07	831.762	1542.805
Storey 09	27	7048.225	3447.865	727.117	1368.214
Storey 08	24	6594.206	3218.66	621.925	1188.886
Storey 07	21	6046.786	2945.82	517.515	1006.771
Storey 06	18	5406.397	2629.812	415.527	824.626
Storey 05	15	4673.536	2271.206	317.935	646.055
Storey 04	12	3848.548	1870.674	227.091	475.547
Storey 03	9	2930.721	1428.906	145.677	318.466
Storey 02	6	1913.287	946.451	77.268	181.575
Storey 01	3	775.096	421.945	47.846	87.485
Base 0	0	0	0	0	0

Fig -11: Displacement comparison for four models

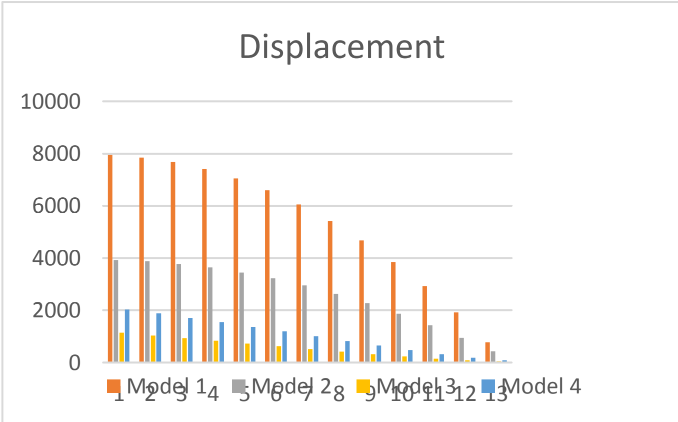

Fig -12: Displacement comparison for four models

Drift in mm					
Storey	Elevation	Model 1	Model 2	Model 3	Model 4
Storey 13	39	0.032752	0.019025	0.034468	0.05374
Storey 12	36	0.058579	0.032273	0.034417	0.054664
Storey 11	33	0.088964	0.046992	0.034782	0.056513
Storey 10	30	0.120113	0.061735	0.035124	0.058495
Storey 09	27	0.15134	0.076402	0.035274	0.060173
Storey 08	24	0.182474	0.090947	0.035038	0.061225
Storey 07	21	0.213464	0.105337	0.034245	0.061347
Storey 06	18	0.244289	0.119536	0.032717	0.060223
Storey 05	15	0.27502	0.133513	0.030389	0.057506
Storey 04	12	0.306046	0.147257	0.027219	0.052781
Storey 03	9	0.340915	0.161184	0.022839	0.045779
Storey 02	6	0.39143	0.17919	0.017663	0.039514
Storey 01	3	0.258365	0.140648	0.015949	0.029162
Base 0	0	0	0	0	0

Fig -12: Drift comparison for four models

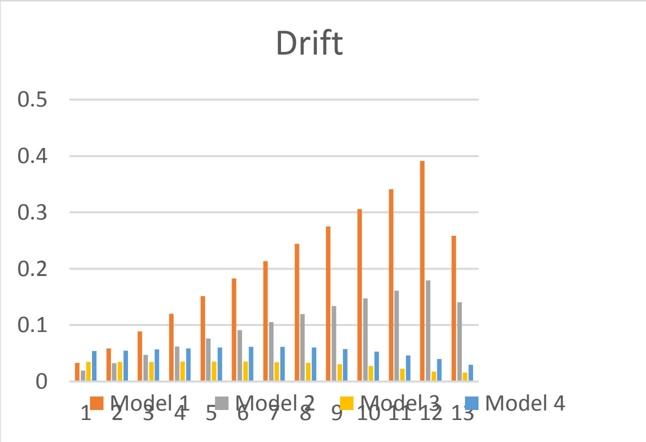

Fig -13: Drift comparison for four models

6. CONCLUSION

- From the four cases studied, it shows that as the blast load increases and the standoff distance decreases the storey displacements and storey drifts increase drastically.

- The blast parameters and effect of blast depends on the charge weight and standoff distance values.

- From the models studied, it shows remarkable change in the storey displacement and storey drift, due to adding of different structural elements, there is reduction in the storey displacement and storey drift

- In the model 2, where column and beam sizes are increased, the results show that structure will improve the resistance, but as huge cross section of columns and beams is needed it will not be possible in many circumstances.

- In the model 3, where the shear walls are added at the corners of the structure, the results show effective improvement in the resistance and can be considered for the structure to be designed for blast resistance.

- In the model 4, where the steel bracings are added at the corners of the structure, the results show improvement in the resistance and can be considered for the structure to be designed for blast resistance.

- It is observed that adding shear wall and steel bracings give effective results and shows decrease in the storey displacement and storey drift. But it is clearly observed that the addition of shear walls give the good results and show minimum storey displacement and storey drift in the structure compared to the other models.

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