A STUDY ON THE DYNAMIC BEHAVIOR OF TALL BUILDINGS

Abdul Muizz[1], Dr. B K Raghu Prasad[2], Dr Amarnath K[3]
[1]M.Tech Student, [2]Professor, [3]Head of Department
Department of Civil Engineering,
The Oxford College of Engineering, Bangalore, Karnataka, India

Abstract : It is necessary to design structures not only to seismic forces but also to suddenly applied shock waves. This has lead to various structural methodologies for safeguarding a structure against such sudden shock loads besides seismic loads. We generally design structures for loads whose magnitudes are much smaller than those caused due to a shock wave. Hence, such conventional structures cannot perform well under the influence of a sudden shock load, and are susceptible to damage. In the present thesis, a tall building (G+30) of plan dimensions 5m x 5m is considered. Each storey is 3m in height. The column dimensions are varied from 600mmx600mm to 1000mmx1000mm. The analysis is done using ETABS 2016 software. The structure is analyzed for shock loads, where the shock pressures are calculated for various charges and stand-offs using IS: 4991-1968. The non-linear displacement and drift are studied. It is found that the values of non-linear displacements and drifts increased as the charge increases and stand-off distance decreases. Next, the structure is studied for seismic forces. The mode shapes, natural frequencies, modal masses, displacements and drifts are studied. It is found that the displacement values are higher for shock loads (100kg at 50m) than for seismic loads in Zone-V. Pushover analysis was done by certain long hand procedures instead of simply using auto-hinge facility of ETABS software on the 30 storey structure to determine the ductility ratio. The ductility ratio is determined to be 2.194 for column sizes 600x600mm.

Index Terms **– Ductility Ratio, Pushover Analysis, Seismic Loading, Shock Loading, Stand-off Distance.**

1. Introduction

1.1. General

It is necessary to design structures not only to seismic forces but also to suddenly applied shock waves. This has lead to various structural methodologies for safeguarding a structure against such sudden shock loads besides seismic loads. We generally design structures for loads whose magnitudes are much smaller than those caused due to a shock wave. Hence, such conventional structures cannot perform well under the influence of a sudden shock load, and are susceptible to damage. Bearing the above condition in mind, various engineers and architects have been exploring various ways to establish structural safety and also the safety of the dwellers dwelling in the structures as well.

1.2. Shock Wave

When a substance or charge is exploded, it results in a rapid expansion of hot gases these gases cause the formation of a compression wave. Such a wave is called, Shock Wave, which propagates through air.

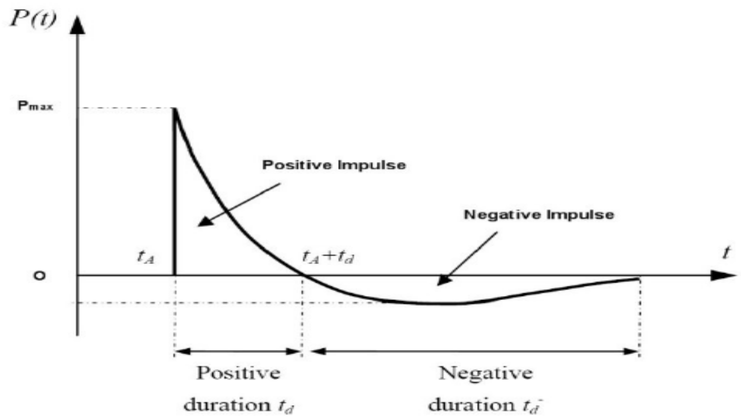

Fig.1.1. Shock Wave produced by a shock

Generally, we consider the front of a shock wave to be infinitely steep, under all practical conditions. Assuming the explosive charge to be spherical in nature, the shock wave generated will also be spherical. Here the energy per unit area continually decreases, as the surface is continually increasing. Accordingly, there is a decrease in the peak pressure (the pressure in front of the wave), as the shock wave propagates outwards from a charge. The wave can be treated as a sound wave, when the distance from the charge is extremely great, as the peak pressure becomes infinitesimal.

As the shock wave passes, the pressure reaches back to its initial value and further goes on decreasing below that of the atmospheric pressure and then rises again to a steady value equal to that of the atmosphere. Hence the shock wave can be distinguished to have two phases; the phase in which the pressure is greater than that of the atmosphere is called the Positive Phase, and, the one where the pressure is lesser than that of the atmosphere is called the Negative Phase / Suction Phase. The negative phase lasts longer than the positive phase. Experimental investigations have concluded that the main structural damage is caused by the positive phase and hence we prefer to ignore the negative phase for design purposes. Only in the conditions where the overall structural integrity has to be studied we consider the negative phase, else it is safe to exclude it for designing.

1.3. Difference between the effect of seismic and shock loads on a structure

Shock and seismic loads are two different types of loadings by themselves. The basic difference being the way a particular structure gets loaded. An earthquake causes ground motions which are incident on the structure causing it to shake from the base to above stories. Whereas when a shock load is to be considered, the shockwaves are being subjected as load on the structure over the exposed area. Some parts of this shock energy also travels through the ground causing the structure to be subjected to certain amount of ground motion as well, which is similar to earthquake but has a comparatively lesser intensity.

The next difference that can be duly noted is the duration of loading. An earthquake induces shaking motion on the structure which can last from a few seconds to a few minutes. But a shock load produces shock waves that generally last for an order of about few milliseconds.

When a building is subjected to earthquake load, the building shakes as a single system and this type of loading mainly causes horizontal loads to be produces at floor-slab levels. Whereas, when a structure is subjected to shock loading, the whole structure does not uniformly get affected, but it produces heavy damage to the nearby structural elements (horizontal or vertical) irrespective of their stiffness. Also, shock loading produces an uplift pressure on floors.

2. Objectives

- To obtain the behaviour of a multi-storied structures under shock and seismic loads.
- To determine sections that could be possibly safe against certain shock loads while also being safe for seismic loads.
- To check the difference in response of the structures by shock and seismic loads.
- To conduct push-over analysis to determine the ductility ratio.

3. Methodology

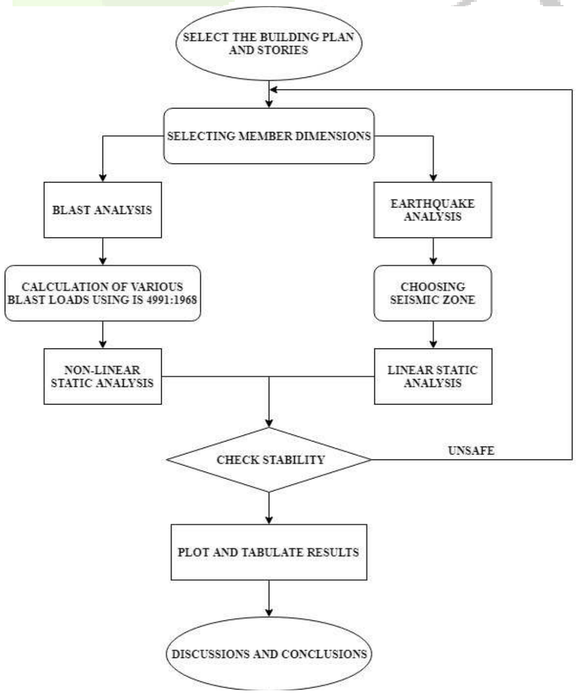

Fig.3.1. Flow chart representing the methodology

3.1. Building Model

A general 30 storied single bay model is taken for analysis for all the chapters coming forth. The software used for analysis is ETABS 2016. Table 3.1 gives the description of the model under study.

Table.3.1. Description of the Model

Number of bays along x-direction	1
Number of bays along y-direction	1
Width of single bay in both directions	5.00 m
No. of storeys	30
Height of each storey	3.00 m

Fig.3.2. shows the Plan view of the model considered for the study and Fig.3.3. shows the 3D view of the model.

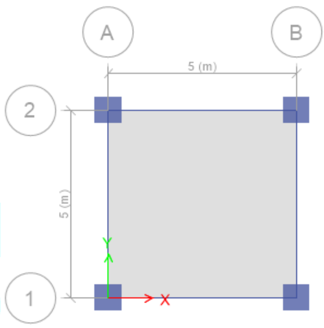

Fig.3.2. Plan view of the model

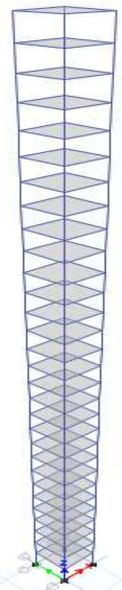

Fig.3.3. 3D view of the model

3.2. Pressure Calculations for Shock Loadings (As per IS:4991-1968)[13]

Shock of 10kg explosive at a standoff distance of 20m

a. Characteristics of the shock

Scaled Distance, x = Standoff / 0.01 $^{(1/3)}$ = 92.83m
From Table-1 (IS: 4991-1968) assuming p_a = 1.00 kg/cm^2 and linearly interpolating values as shown below

Distance	p_{so}	t_0	t_d	q_0	p_{ro}
m	kg/cm^2	milli-secs	milli-secs	kg/cm^2	kg/cm^2
90	0.22	43.6	33.39	0.016	0.47
92.83	0.20	44.31	34.63	0.01	0.43
93	0.2	44.35	34.7	0.014	0.43

The values obtained in the above table are for 1.00 kg/cm^2 charge
For 10kg charge, multiply t_d and t_0 by 0.01 $^{(1/3)}$
Therefore,
t_0 = 9.55 milliseconds
t_d =7.46 milliseconds
M = SQRT(1 + ((6/7)*(p_{so} / p_a)))
Where, p_a = 1.00 kg/cm^2 {Note-1, Pg.10, IS: 4991-1968}
Therefore,
M = 1.08
U = M x a {Where, a =Velocity of Sound in air = 344 m/s}
Therefore,
U = 372.47 m/s = 0.372 m/milliseconds

b. Various pressures acting upon building faces

In the present case
Storey Height = 3m ; Width = 5m ; Length = 5m;

Then, S = least of Height or Width/2 = 2.5m
t_c = 3S/U = 20.14 milliseconds (> t_d)
t_c = L/U = 13.42 milliseconds (> t_d)
t_r = 4S/U = 26.85 milliseconds (> t_d)
Here, tr>td
Hence, the pressure acting on the back face is not taken into consideration
For roof and sides, C_d = -0.4
$p_{so} + C_d q_0$ = 0.20 kg/cm^2

Similarly, pressure values are calculated for various charges and stand-off distances. Table.3.2, Fig.3.4 and Fig.3.5 gives the variation of pressure for different charges at different standoff distances as calculated before.

Table.3.2. Table giving the pressure values for different charge and stand-off

CHARGE	20m		30m		40m		50m	
	Front Face	Side Face	Front Face	Side Face	Front Face	Side Face	Front Face	Side Face
kg	kN/m^2	kN/m^2	kN/m^2	kN/m^2	kN/m^2	kN/m^2	kN/m^2	kN/m^2
10	42.18	19.62	39.24	17.66	39.24	17.66	39.24	17.66
20	62.78	27.47	39.24	17.66	39.24	17.66	39.24	17.66
30	79.46	33.35	40.22	17.66	39.24	17.66	39.24	17.66
40	95.16	38.26	48.07	21.58	39.24	17.66	39.24	17.66
50	110.85	43.16	53.96	23.54	39.24	17.66	39.24	17.66
60	125.57	48.07	58.86	25.51	39.24	17.66	39.24	17.66
70	140.28	51.99	64.75	27.47	40.22	17.66	39.24	17.66
80	154.02	56.90	69.65	29.43	42.18	19.62	39.24	17.66
90	166.77	59.84	73.58	31.39	47.09	21.58	39.24	17.66
100	182.47	64.75	79.46	33.35	50.03	22.56	39.24	17.66

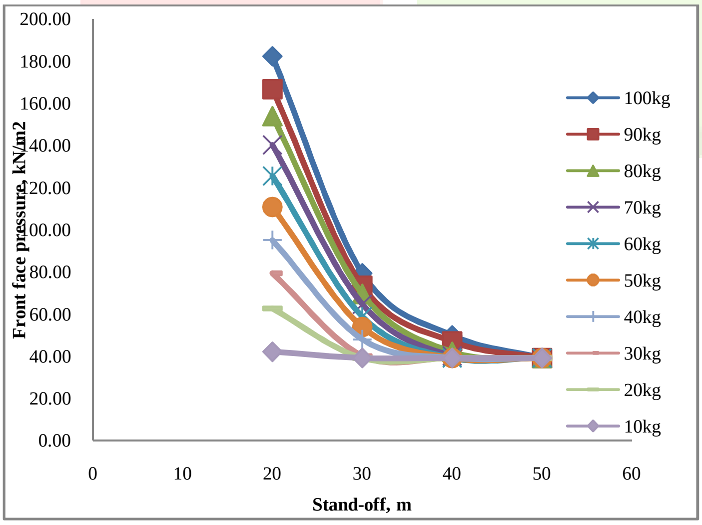

Fig.3.4. Graph representing the variation of front face pressure with charge and stand-off

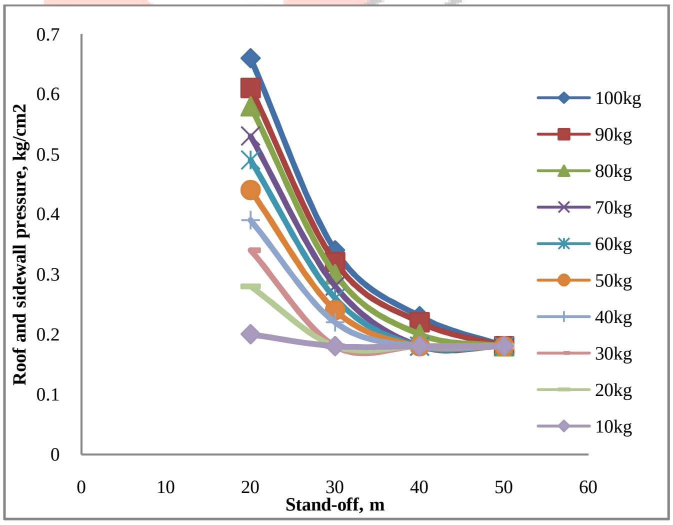

Fig.3.5. Graph representing the variation of pressure pulse on roof and sidewalls with charge and stand-off

3.3. Structural and Material details

Table.3.3 and Table.3.4 gives the structural and material details respectively, which were used in the analysis.

Table.3.3. Structural Details

Model	Column Size	Beam Size	Slab thickness
1	600mm x 600mm	230mm x 600mm	150mm

2	800mm x 800mm	230mm x 600mm	150mm
3	1000mm x 1000mm	230mm x 600mm	150mm

Table.3.4. Material Details

Grade of Concrete, f_{ck}	Column	M40
	Beam and Slab	M30
Grade of Steel, f_{st}		Fe 500
Concrete Density		25 kN/m^3
Steel Density		78.5 kN/m^3

4. SHOCK LOAD ANALYSIS

4.1. Application of Shock Loads

The structure (as mentioned in topic 3.2.) is subjected to various shock loads which are assumed to be acting per unit area of the structure. Hence first the shock load is converted from kg/cm^2 to kN/m^2 by multiplying 98.1, then the wall length is multiplied (i.e. 5m) and we get the load in terms of kN/m which is assumed to be transmitted to the columns equally. The table below gives the loading values applied on each individual column for different charges and standoff distances.

Table.4.1. Load to be applied on each individual column

CHARGE	20m		30m		40m		50m	
	Front Face	Side Face	Front Face	Side Face	Front Face	Side Face	Front Face	Side Face
kg	kN/m	kN/m	kN/m	kN/m	kN/m	kN/m	kN/m	kN/m
10	105.4	49.05	98.10	44.14	98.10	44.14	98.10	44.14
20	156.96	68.67	98.10	44.14	98.10	44.14	98.10	44.14
30	198.65	83.38	100.55	44.14	98.10	44.14	98.10	44.14
40	237.89	95.64	120.17	53.95	98.10	44.14	98.10	44.14
50	277.13	107.91	134.88	58.86	98.10	44.14	98.10	44.14
60	313.92	120.17	147.15	63.76	98.10	44.14	98.10	44.14
70	350.70	129.98	161.86	68.67	100.55	44.14	98.10	44.14
80	385.04	142.24	174.12	73.57	105.45	49.05	98.10	44.14
90	416.92	149.60	183.93	78.48	117.72	53.95	98.10	44.14
100	456.16	161.86	198.65	83.38	125.07	56.40	98.10	44.14

4.2. Assigning shock loads

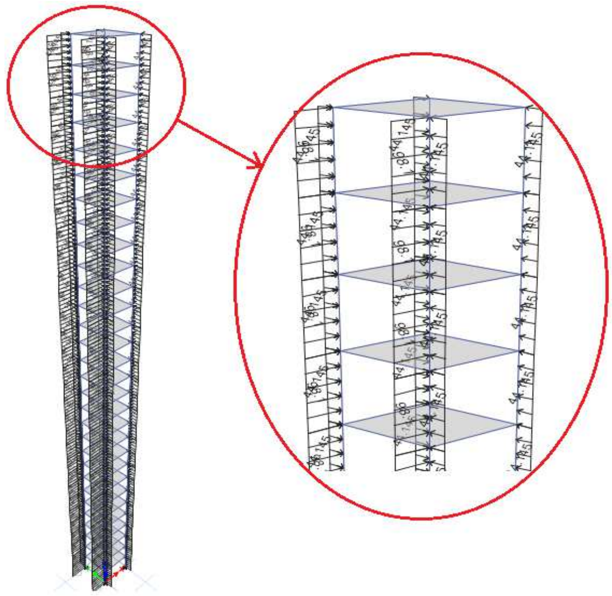

Fig.4.1. Assigning Shock loads on the structure (100kg at 50m)

In the computer coding, the shock loads are defined as "SHOCK" in the load patterns and were assigned on the columns as a UDL, as shown in Fig.4.1, which shows the loading being applied for the case of 100kg charge at 50m stand-off.

4.3. Analysis

The model after loading with different loads, is now set to various load cases. The dead and live loads are set to linear static load case whereas the shock loading is subjected to non-linear static load cases. Auto-plastic hinges are provided for the frame elements at relative distances of 0.1 and 0.9 respectively. The structure run for analysis and the results studied.

4.4. Discussions

4.4.1. Variation of storey displacements

After applying various loads, the analysis was done and the displacement results tabulated. It was found that the value of displacement increases with increase in charge and decrease in stand-off. This can be clearly seen in the graph depicted in Fig.4.2.

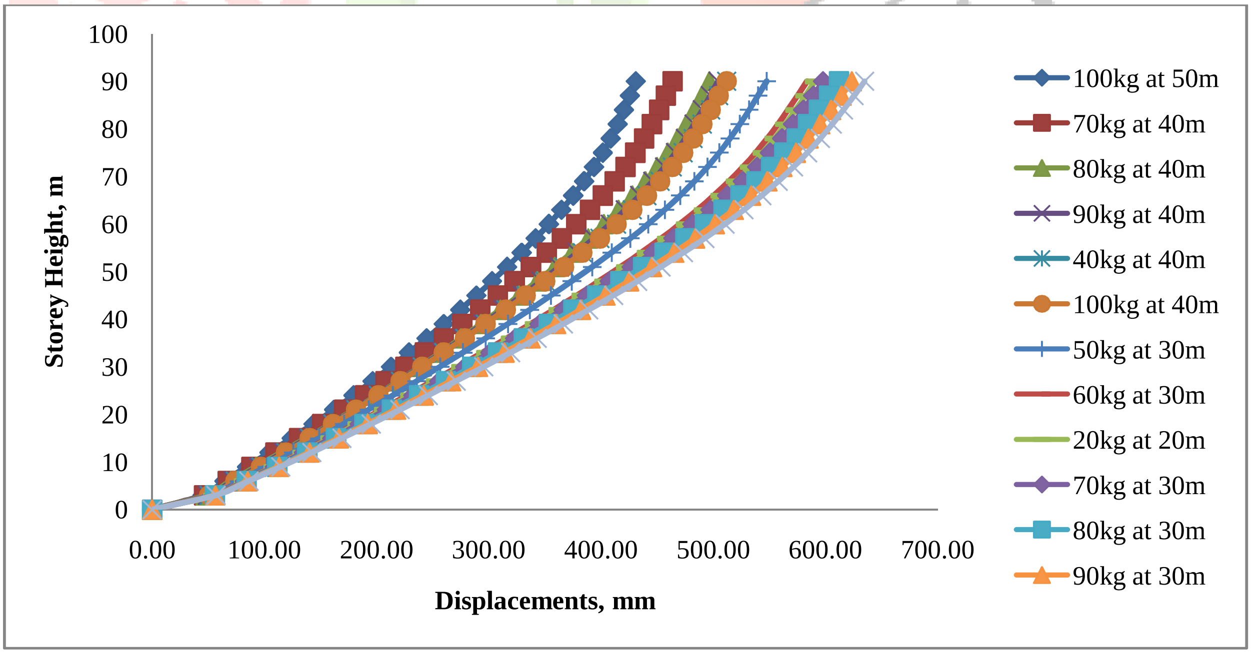

Fig.4.2. Variation of Storey Displacements with charge and stand-off

4.4.2. Variation of storey drifts

After applying various loads, the analysis was done and the drift results tabulated. It was found that the value of maximum drift increases with increase in charge and decrease in stand-off. This can be clearly seen in the graph depicted in Fig.4.3.

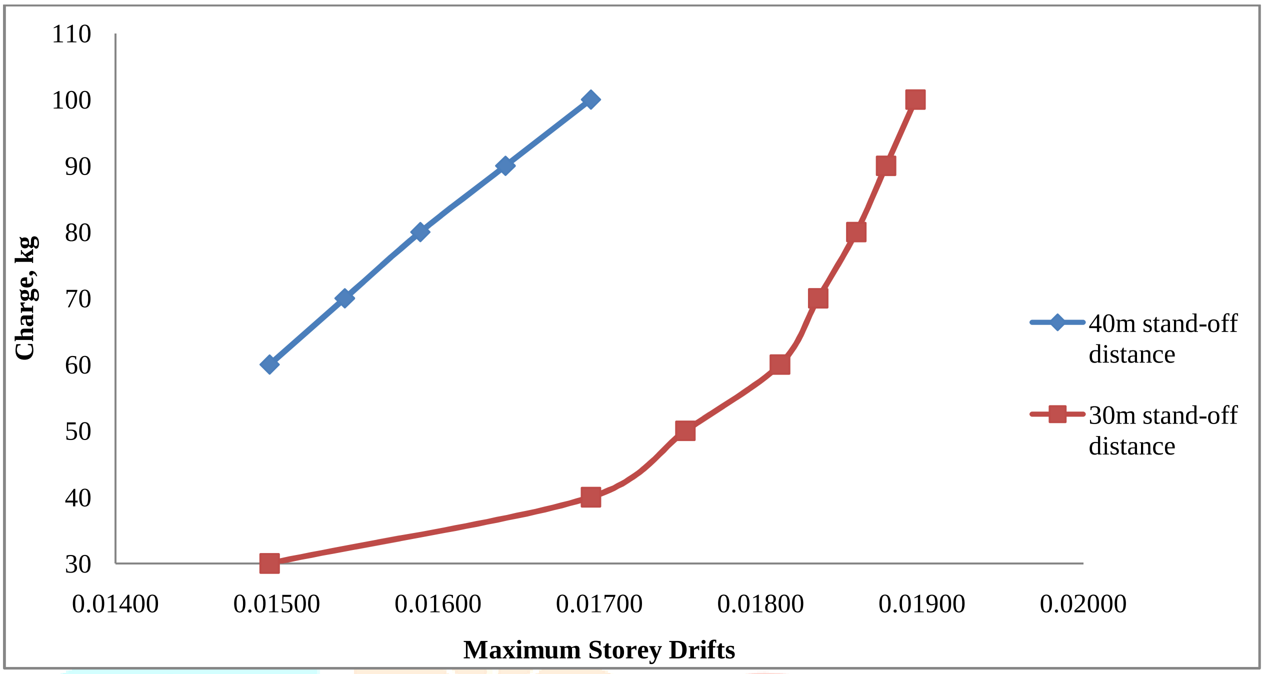

Fig.4.3. Variation of Maximum Storey Drifts with charge and stand-off

5. EARTHQUAKE ANALYSIS

5.1. Preliminary Data

The following data has been considered for the analysis:

Table.5.1. Preliminary Seismic Data for analysis

Importance Factor, I	1.0
Response Reduction Factor, R	5.0
Soil Type	II
Fundamental Natural Period, T_a	2.1915 seconds

From, IS 1893 (Part 1):2016

$T_a = 0.075h^{0.75} = 0.075*90^{0.75} = 2.1915$ seconds

5.2. Analysis

The model (mentioned in section 3.2.) after loading with the loads, is now set to various load cases. The loads are set to linear static load case and the earthquake for various seismic zones.

5.3. Discussion

5.3.1. Variation Of Storey Displacement

Fig.5.1 depicts the variation of storey displacement with increase in section of the column and the seismic intensity. The displacement can be seen to increase with the severity of the seismic intensity and also its value decreases as the size of the column members increases.

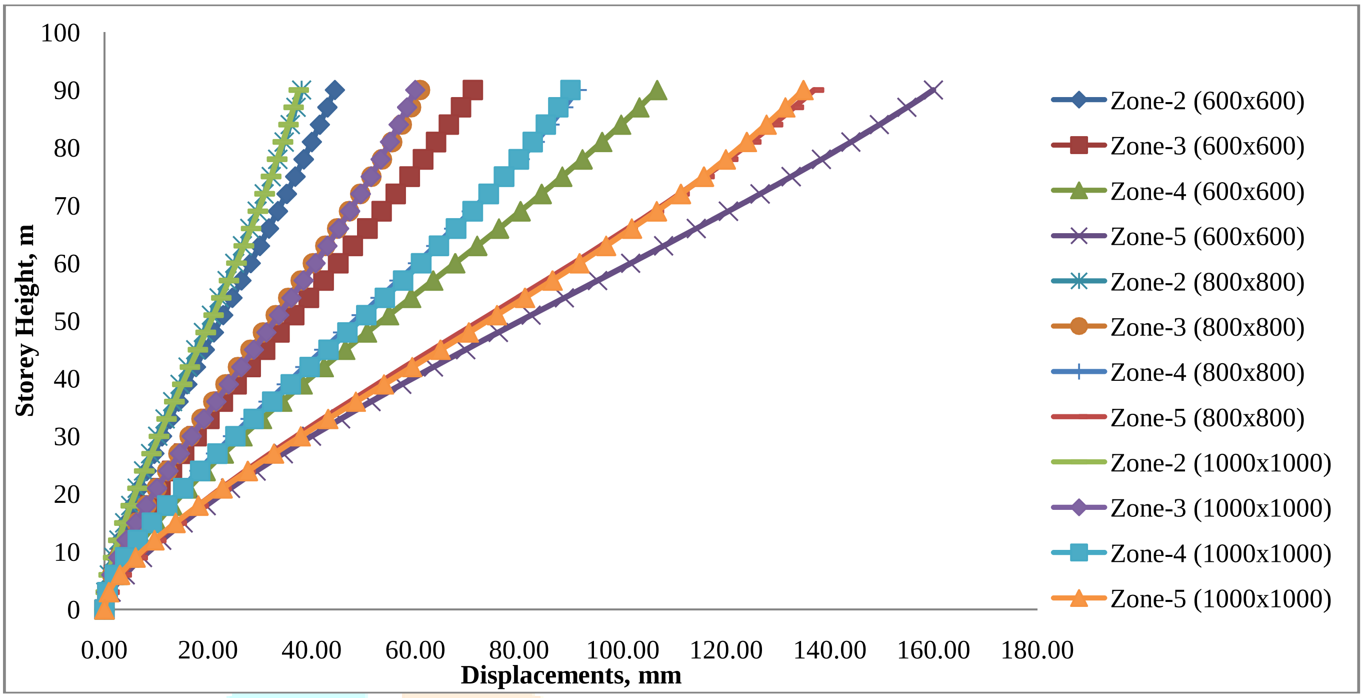

Fig.5.1. Variation of Storey Displacements under seismic loading

5.3.2. Variation Of Storey Drifts

Fig.5.2 depicts the variation of storey drift with increase in section of the column and the seismic intensity. The drift can be seen to increase with the seismic force and also its value decreases as the sizes of the column members increase.

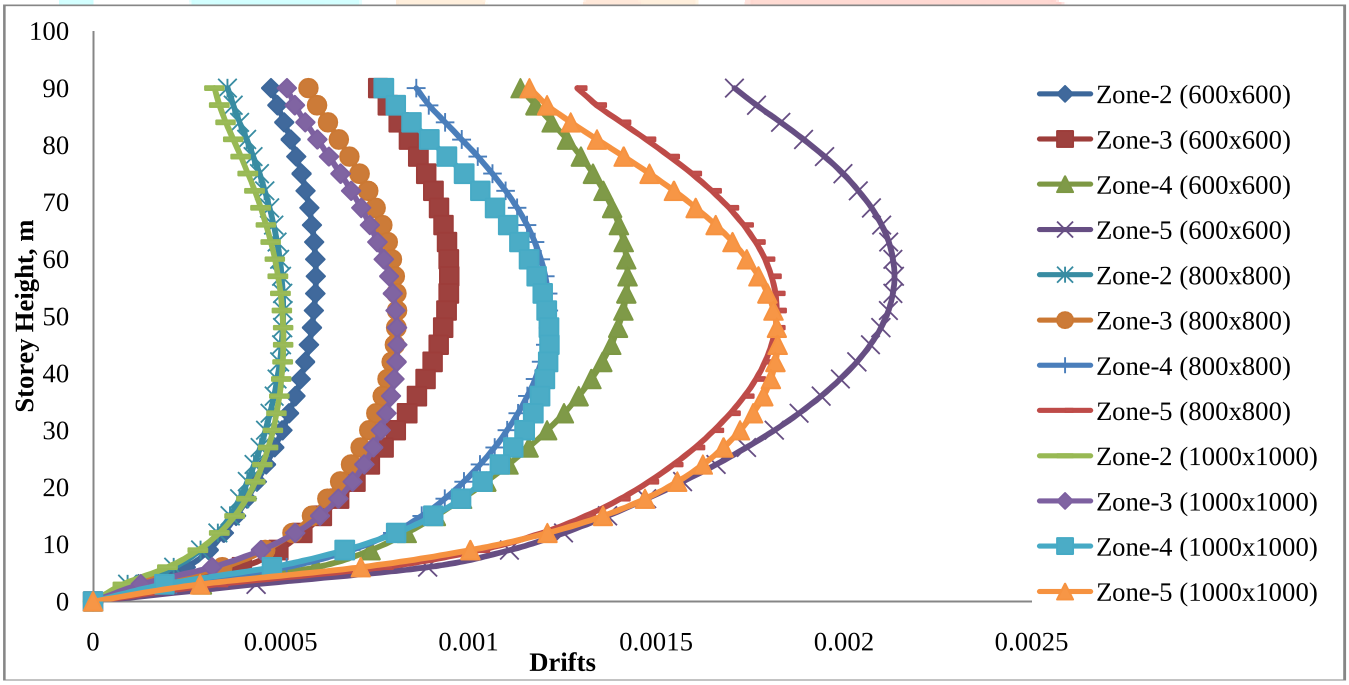

Fig.5.2. Variation of Storey Drifts under seismic loading

6. Comparison Between Shock And Seismic Load With Increase In Section

6.1. Preliminary Data

Five different cases of the same G+30 model were considered for the analysis. They were subjected firstly to a shock load of 100kg at 40m stand-off, then later were subjected to earthquake forces by assuming the structure to be under Zone – V. The details of the various cases are presented in Table.6.1.

Table. 6.1. Section Details

Model	Column Dimension, mm	Beam Dimension, mm	Slab thickness, mm

1	600 x 600	300 x 600	150
2	700 x 700	300 x 600	150
3	800 x 800	300 x 600	150
4	900 x 900	300 x 600	150
5	1000 x 1000	300 x 600	150

6.2. Discussions

6.2.1. Variation Of Displacement

Fig.6.1. show the displacement results for the various cases that were found using ETABS software. It was seen that the displacement values were reducing with increase in the section dimension. Shock loading had a higher displacement when compared to seismic loading. This is probably because the load intensity of the shock load is several times greater than that of the seismic loads.

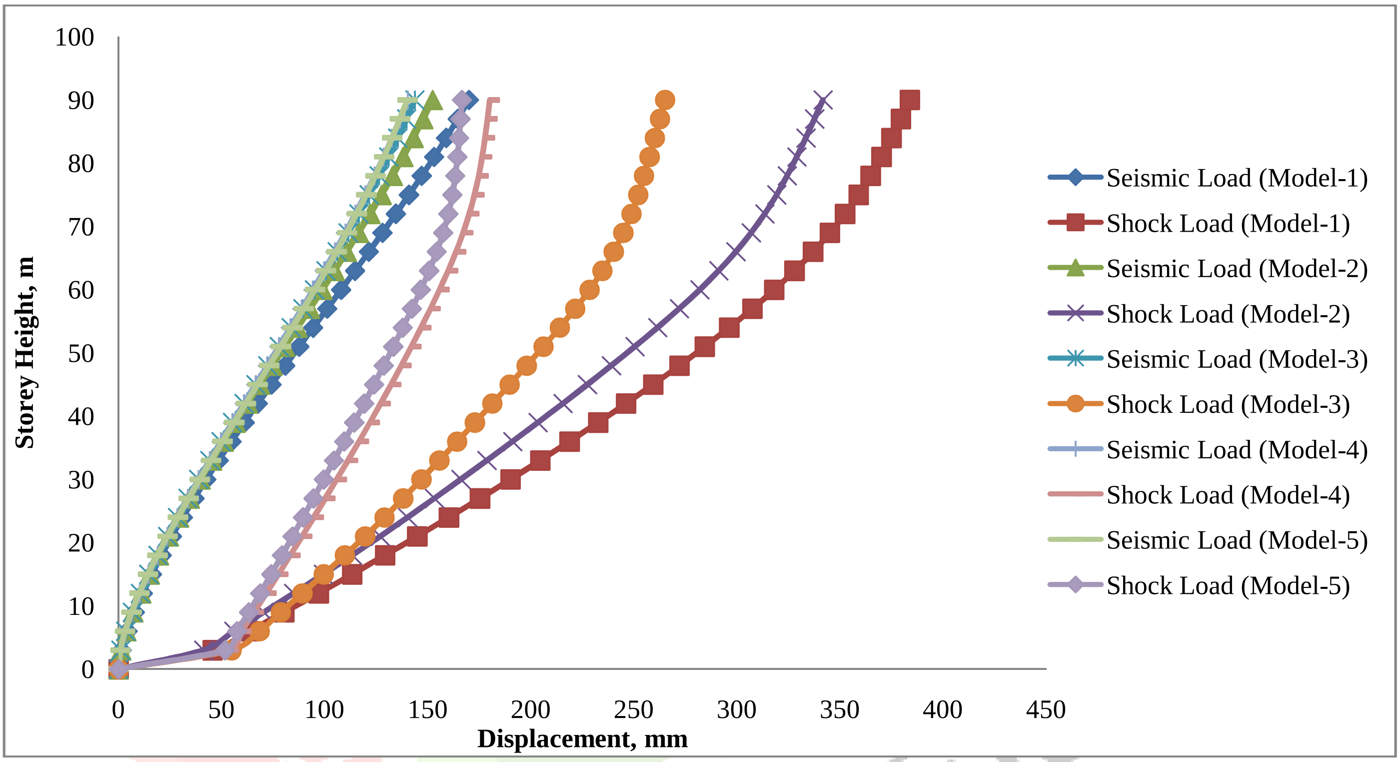

Fig.6.1. Variation of Storey Displacement for Shock and Seismic Loading

7. PUSHOVER ANALYSIS

7.1. Analysis

The model-1 having column dimensions 600x600 as mentioned in Table.6.1 is selected and was tested for pushover analysis. Pushover analysis was carried out manually without in ETABS in the following manner:

- The model was prepared in ETABS in the usual way.
- Push-X load pattern was defined.
- The load case was given as non-linear static and full load was applied.
- Joint load was applied on the top joint as shown in Fig.7.2.
- Loading was incremented in a constant manner until the maximum moment in the beam was within $M_{u,lim}$ (As calculated in Annex-B), and the resulting maximum displacement was noted.
- Once the value of the maximum beam moment crossed $M_{u,lim}$, with a 10% allowance hinges were provided to those beams. The analysis done and the displacement noted. (Seen in Table.7.1)
- This was constantly done till all the beams had been provided with hinges.
- A graph was plotted between force and displacement as shown in Fig.7.3. from this graph we obtain the displacement ratio.

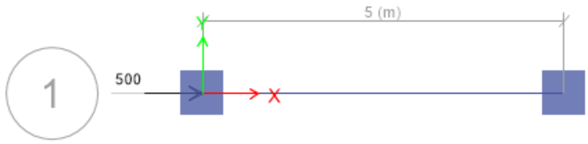

Fig.7.1. Plan View of the model subjected to pushover analysis

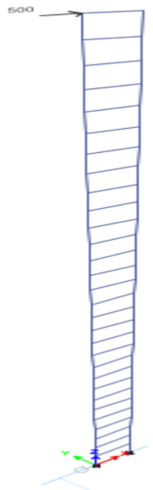

Fig.7.2. 3D view of the model subjected to pushover analysis

7.2. Variation of Load Vs Displacement Curve

Table.7.1. shows the results for the variation for load with displacement as obtained from ETABS.

Table.7.1. Variation of Load vs Displacement

Step	Displacement mm	Force kN	No. of hinges given
0	0	0	0
1	127.469	50	0
2	254.938	100	0
3	382.407	150	0
4	509.875	200	0
5	637.344	250	0
6	764.813	300	0
7	892.282	350	0
8	968.763	380	0
9	994.330	390	2
10	1071.868	420	2
11	1123.879	440	6
12	1162.436	450	34
13	1365.760	460	60
14	2465.457	500	60

Fig.7.3. shows the graphical representation of the variation of load vs displacement curves for various sizes of sections.

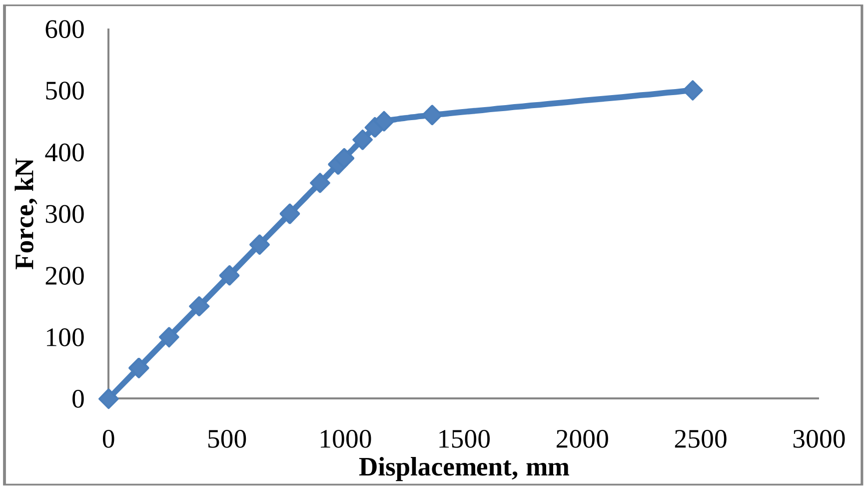

Fig.7.3. Variation of load vs displacement curves

From the above graphs we obtain the ductility ratio as follow,
Ductility Ratio = (2465.457/1123.879) = 2.194

8. CONCLUSION

- The value of pressure for the shock loads goes on increasing with increasing charge and decreasing stand-off distance.
- The value of displacement goes on increasing with increase in charge and decrease in stand-off for the structures subjected to shock loads
- The drift values for structures subjected to shock loads increase with increase in charge and decrease in stand-off.
- The bottom most stories subjected to shock loads are susceptible to greater deformations.
- For a structure subjected to earthquake, the value of displacement and drift goes on increasing with increase in the seismic intensity. Zone-5 having the maximum top storey displacement.
- For a same structure subjected to shock and seismic forces, the value of displacement was found to be greater for a structure subjected to shock loading. It was seen that with increasing dimensions, the structure was found to have lesser displacement.
- Pushover analysis for the selected model gave out the ductility ratio of 2.194.

9. REFERENCES

1. Mir M. Ali (2002), “Protective Design of Concrete Building under Blast Loading”.

2. Alexander M Remennikov (2003),“A Review of Methods for Predicting Bomb Blast Effects on Buildings”.

3. T. Ngo, P. Mendis, A. Gupta, J. Ramsay (2007), “Blast Loading and Blast Effects on Structures”.

4. Quazi Kahif, Dr M B Varma (2014), “Effect of Blast on G+4 RCC Frame Structure”.

5. Aditya C Bhatt, Snehal V Mevada, Sumant B Patel (2016), “Comparative Study of Response of Structures Subjected to Blast and Earthquake Loading”.

6. Demin George, Varnitha M S (2016), “Structural Analysis of Blast Resistant Structure”.

7. Jiji Madonna, Vijaya G S, Kirankumar K L (2016), “Analysis of High Rise RCC Building subjected to Blast Load”.

8. Naveenkumar Khatavakar, Dr B K Raghu Prasad, Dr Amarnath K (2016), “Response of High Rise Structures subjected to Blast Loads”.

9. Danesh Nourzadeh, Jagmohan Humar, Abass Braimah (2017), “Comparison of Response of Building Structures to Blast Loading and Seismic Excitations”.

10. Ganavi S, P S Ramesh, Dr V Devaraj, Yogish C B (2017), “Behaviour of Framed Structure Subjected to Explosion on the Ground”.

11. Ganganath C P, Lekshmi L (2017), “Parametric study on RCC, Steel and Composite Structures under Blast Loading”.

12. Gautham T N, Dr M N Hegde (2017), “Blast Resistant Buildings”.

13. IS 4991 (1968): Criteria for blast resistant design of structures for explosions above ground.

14. IS 1893 Part-1 (2016): Criteria for earthquake resistant design of structures.