Blast Analysis Of Structures

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Abstract

Terrorism is the most dangerous problem the world is facing today. It has caused the feeling of insecurity among the people despite of the advancement in technology, counterintelligence the problem remains unsolved. Despite the fact that the magnitude of the explosion and the loads caused by it cannot be anticipated perfectly efforts can be made to reduce the consequences of the explosion. Due to advancement in technology and introduction of finite elements software it is now possible to get to a reliable conclusion. The analysis and design of structures subjected to blast loads require a detailed understanding of blast phenomena and the dynamic response of various structural elements. The study is made to understand the properties of blast wave by estimating the blast wave parameters for various charge amounts placed at various distances. The effect of TNT (trinitrotoluene) explosive on a column foundation for various amount of TNT charge at various distances is investigated for model buildings of various floors and presented in this paper.

Introduction

Blast protection have become an important consideration for structural designers due to increase in terrorist attacks in the recent days. Conventional structures normally are not designed to resist blast loads and because the magnitudes of design loads are significantly lower than those produced by most explosions, conventional structures are susceptible to damage from explosions. In the past, few decades considerable emphasis has been given to problems of blast and earthquake. The earthquake problem is rather old, but most of the knowledge on this subject has been accumulated during the past fifty years. The blast problem is rather new, information about the development in this field is made available mostly through publication of the Army Corps of Engineers, Department of Defence, other governmental office and public institutes. B. M. Luccioni et al. [1] analyzed an actual building which suffered terrorist attack. The analysis is compared with the photographs of real damage. Analysis is done using AUTODYN software. T. Ngo et al. [2] 2007 presented an overview of the effects of explosion on structures. An explanation of the nature of explosions and the mechanism of blast waves in free air is given. This study also introduces different methods to estimate blast loads and structural response. In the study the behavior of concrete column under blast loads was made. Ghani Razaqpur et al.[3] 2007, investigated the behavior of reinforced concrete panels, or slabs, retrofitted with glass fiber reinforced polymer (GFRP) composite, and subjected to blast load eight 1000 x 1000 x 70 mm panels were made of 40 MPa concrete and reinforced with top and bottom steel meshes. Blast wave characteristics, including incident and reflected pressures and impulses, as well as panel central deflection and strain in steel and on concrete/FRP surfaces were measured. Nitesh N. Moon [4] 2009 in his master degree thesis give the procedure for calculating the blast loads on the structures with or without openings and frame structures. He also made comparison between the normal strength column and high strength column which show that the critical impulse in case of the higher strength column is significantly higher. Andrew Sorensen et al. [5] 2012 discussed various software used for blast analysis he also emphasized the use of software by personal having knowledge and experience.

In present work a study of distant blast on the structure is made to find the variation of forces in column foundation like axial force, shear force and bending moment by varying amount of explosive and also by varying the distance of explosion from the building. Building of various height are analyzed so that effect of height to resist blast is also studied. Load is applied in the form of time history loading.

Methodology and assumption for analysis:

In this paper the blast wave parameters for TNT (trinitro-toulene) charge of 0.1Tonne (T), 0.2T, 0.4T, & 0.6T at distances of 30m, 35m and 40m are estimated. The blast wave parameters like scaled distance, peak-overpressure, peak- reflected overpressure, positive phase duration, equivalent triangular phase duration, Mach number are calculated using IS 4991.

Using blast wave parameters an analysis is made on a model building with three bay each having 3m span & floor height is assumed to be 3m. Like-wise building of 3, 4, 5 6, 7,8,10 & 12 are modeled in Staadpro. The effects of ground shock due to explosion are not considered during the analysis in order to justify this assumption the blast is assumed to be occur at 1.5m above ground level. The loads are assumed to be acting at the beam-column junction on the face of the building subjected to blast wave in the form of concentrated load. To calculate this concentrated load the blast pressure is multiplied by the area contributing to the node. The pressure acting on the side face of the building is calculated by the criteria mentioned in IS 4991. The load is applied in the form of time history loading at nodes of beam column junction in order to perform the dynamic analysis using finite element package Staad-pro.

Blast wave parameters calculation:

Properties of blast wave at any point depend on two factors, firstly the distance between the explosion and point if observation and secondly the amount of blast charge. Once the above two factors are determined the blast wave parameters are calculated using IS 4991. In this standard blast wave parameters for 1 tonne TNT explosive is mentioned. Using these values parameters for explosive other than 1 tonne can be reduced using cube root scaling laws which are given as:

$$\text{Scaled distance} = \frac{Actual\ \ distan\ ce}{W^{\frac{1}{3}}}$$

$$\text{Scaled time} = \frac{Actual\ \ time}{W^{\frac{1}{3}}}$$

Where W is the charge weight in tones of TNT equivalence. When the explosive is other than TNT it can be converted into TNT using equivalence factor.

Blast wave parameters for 100kg TNT explosive at 40m distance at various floor levels is tabulated below:

hor. Dist	ver. dist	Pso (Kg/ cm^2)	M	td (sec.)	t_a (sec.)
40	0	0.233	1.10	0.00110	0.105
40	3	0.232	1.10	0.00110	0.105
40	6	0.230	1.09	0.00109	0.106
40	9	0.226	1.09	0.00109	0.108
40	12	0.220	1.09	0.00109	0.110
40	15	0.206	1.08	0.00108	0.113
40	18	0.195	1.08	0.00108	0.117
40	21	0.186	1.07	0.00107	0.121
40	24	0.173	1.07	0.00107	0.125
40	27	0.162	1.07	0.00107	0.130
40	30	0.150	1.06	0.00106	0.135
40	33	0.139	1.06	0.00106	0.141
40	36	0.127	1.06	0.00106	0.146

Table 1: Blast wave parameters for 0.1T of TNT charge

Peak overpressure (Pso) is the pressure of the blast wave propagating in the free air. However when this blast wave comes across an obstruction this blast wave gets reflected resulting in the amplification of pressure which is called reflected overpressure. Arrival time (t_a) for blast wave at each floor is different, arrival time is calculated using Mach number (M) which is the ratio of the speed of the shock front propagation to the speed of sound in standard atmosphere at sea level. Duration of positive phase is converted to the equivalent triangular phase duration (t_d) in order to simplify calculations.

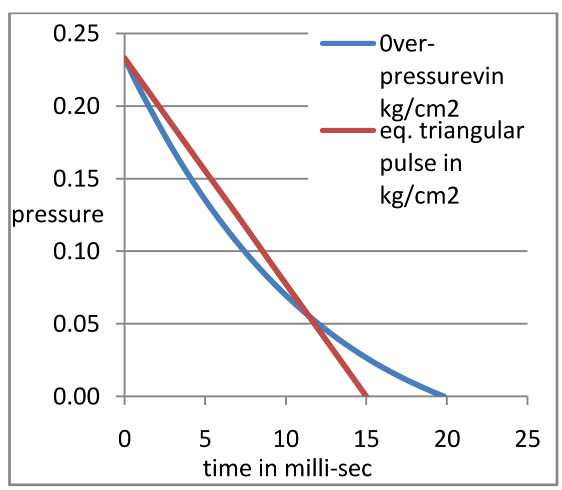


Figure 1: Blast wave positive phase and equivalent triangular phase

Variation of blast pressure for 100Kg TNT explosive at floor levels of 12-storey building due to blast at 30m, 35m and 40m is shown in figure 2.

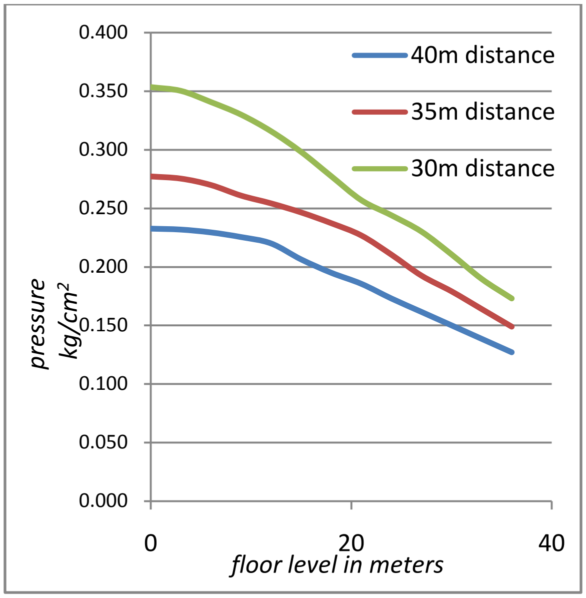


Figure 2: Variation of pressure with height of building

Variation of blast pressure for 100Kg, 200kg, 400kg and 600kg TNT explosive at floor levels of 12-storey building due to blast at 40m is shown in figure 3.

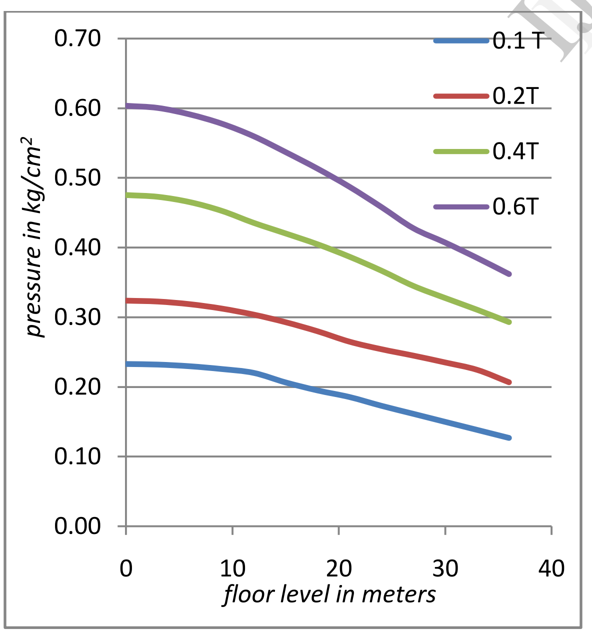


Figure 3: pressure variation due to variation of charge amount

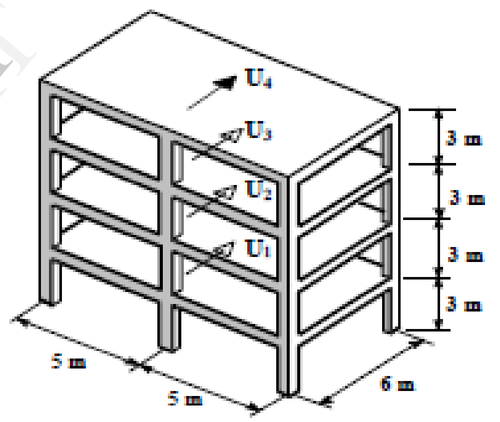
Validation

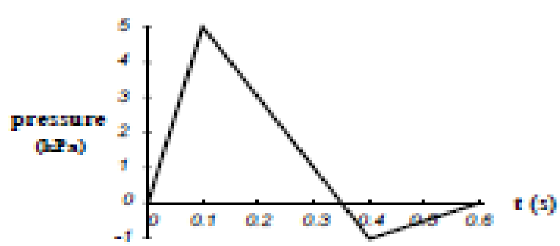
Blast loads are applied on the structure in the form of time history loading. Finite element package Staadpro is used to perform the analysis in this work. In order to validate the use staadpro for blast analysis following experiment is performed.

Example considered is from the book "Multiple degrees of structural dynamics" [6] (ref.1) in which the node displacement at the floors is determined. Same example is also executed using S-Frame software [7] (ref.2). The results of the three methods are compared to validate the use of Staadpro.

Example

The building shown below is subjected to blast load. The pressure wave caused by blast in the form of time history is shown below. Beam and column section have width b = 0.40 m and depth h = 0.50 m. modulus of elasticity of structure is E = 25 GPa. The building has a mass per unit area of 1000 kg/m^2.





The variation of blast pressure along the height of the building is not considered because the blast is assumed to be occurring far away. The blast load is applied in the form of concentrated at the node of the beam column junction. Concentrated load is calculated by multiplying the contributing area at the node with the pressure intensity.

Comparing results with the reference values it is found that deflection obtained in Staadpro show good agreement with reference values.

Floor Disp.(mm)	**Staadpro**	Ref.1	Ref.2
4th floor	**29.782**	29.373	29.333
3rd floor	**25.219**	25.103	25.107
2nd floor	**17.253**	17.455	17.496
1st floor	**6.983**	7.479	7.509

In graphical form comparison is made in the figure below

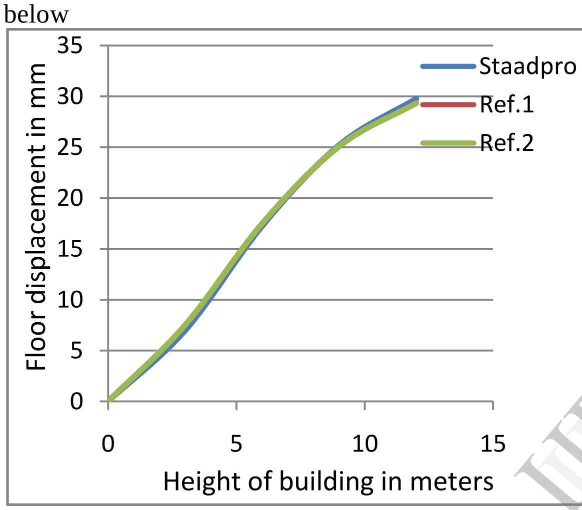


Figure 4: Variation of floor displacement with height of building

As observed from the table and graph it is concluded that the Staadpro software is performing satisfactorily for blast analysis.

Dynamic analysis using time history of blast loads:

After defining time history of loads at nodes analysis is performed on various models building of 3, 4, 5 6, 7,8,10 & 12 floors. The building is assumed to be fixed at the base. The overall dimensions of the building are 9m breadth, 9m length and height according to number of floors. Floor to floor height is assumed as 3m. The footing considered for analysis is of the column which is on the face of building subjected to blast. Along with the blast loads dead loads and live loads are applied as per IS 875. For simplifying the analysis the structure is assumed to be diffraction type with opening less than 5 percent.

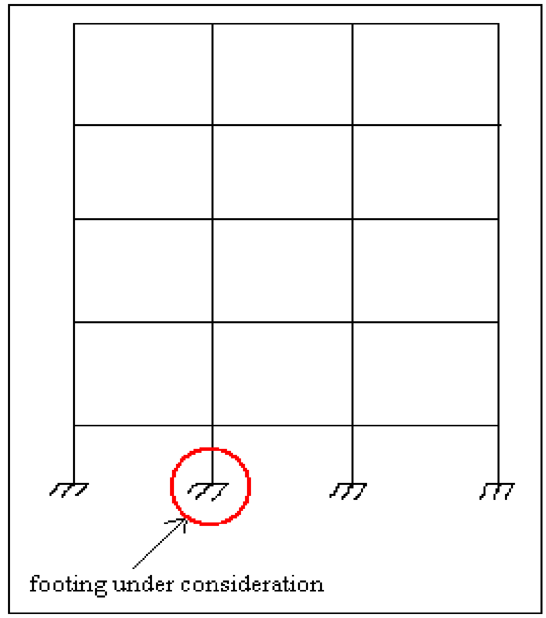


Figure 5: Specimen building of 4-floor with face subjected to blast

Seismic loads are not considered for the analysis as the probability of earthquake and blast occurring simultaneously is negligible. The front face of building subjected to blast for which reflected pressure is considered while on the side face on building dynamic pressure caused by blast wind is considered.

Results and Discussions

By varying the distance of 100kg TNT explosive and also considering buildings of various height following results are obtained:

Type of building	compr. load Dl+LL (KN)	Axial tension in KN		
		Distance of charge		
		40m	35m	30m
3 floors	279.6	83.4	97.2	96.9
4 floors	372.1	88.7	102.6	114.8
5 floors	501.3	101.7	106.3	126.4
6 floors	560.0	101.2	106.5	134.5
7 floors	690.4	55.2	64.1	74.3
8 floors	749.2	64.6	71.7	82.3
10 floors	937.7	74.2	92.8	102.1
12 floors	1124.8	93.5	108.7	126.7

Table 2: Axial tensile load in KN due to blast

Normalizing above results by calculating net force in footing and dividing it by load due to DL+LL we get following values

Type of building	Distance of charge		
	40m	35m	30m
3 floors	0.702	0.652	0.653
4 floors	0.762	0.724	0.692
5 floors	0.797	0.788	0.748
6 floors	0.819	0.810	0.760
7 floors	0.920	0.907	0.892
8 floors	0.914	0.904	0.890
10 floors	0.921	0.901	0.891
12 floors	0.917	0.903	0.887

Table 3: Normalized value of Axial load

In static condition the loads in the footing is predominantly the axial load which is compressive due to dead load and live load. However due to blast tensile load is introduced which results in reducing the compressive load. On the rear face of the building the blast load exert additional compressive load on the footing which may result in failure. Graphically above results are shown below

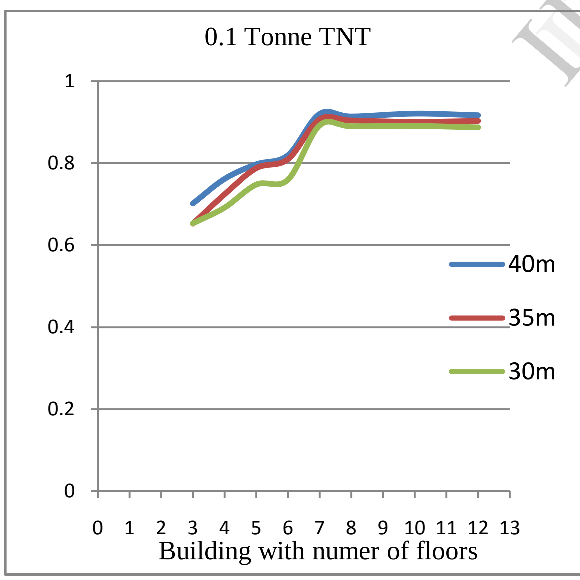


Figure 6: Change in Axial load in footing due to blast

Results for 0.2 Tonne of TNT and 0.4Tonnes of TNT are shown in figure below:

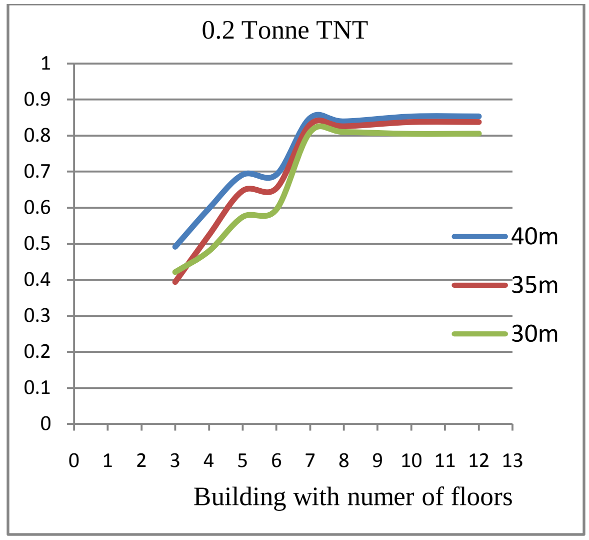


Figure 7: Change in Axial load on foundation due to 0.2T TNT

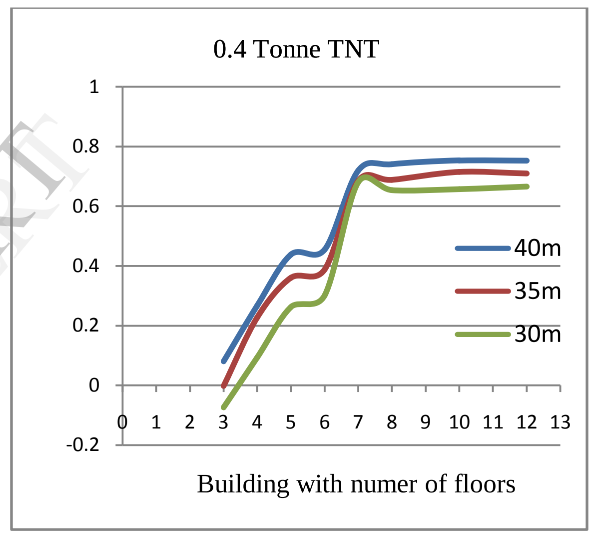


Figure 8: Change in Axial load on foundation due to 0.4 T TNT

From above results it is found that of the entire analyzed buildings highest tensile load is induced in 3 floor building. For 4 floor, 5 floor, 6 floor building tensile load goes on reducing, however the value of tensile load is significant. In case of 7 floors building there is rapid reduction in tensile load. For 8 floor, 10 floor and 12 floor building tensile load almost remain constant.

Results for shear force are given below in KN

Shear force in KN				
Type of building	Distance of charge 40 m			
	0.1T	**0.2T**	**0.4T**	**0.6T**
3 floors	21.43	36.48	66.01	92.62
4 floors	17.78	30.00	54.65	74.83
5 floors	16.76	25.47	46.42	62.66
6 floors	14.17	24.16	42.72	58.14
7 floors	42.26	67.34	112.77	152.06
8 floors	43.36	69.13	112.59	154.50
10 floors	43.31	67.80	115.27	157.25
12 floors	44.36	71.08	117.20	158.46

Table4: Variation of shear stress

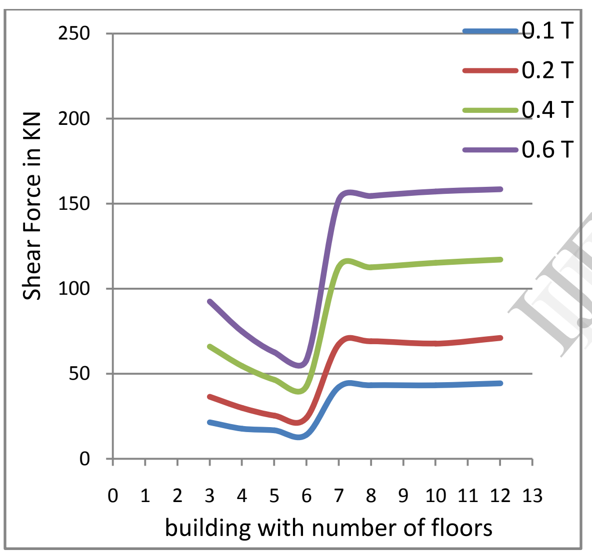


Figure 9: Shear force in footing for 40m distance blast

From the results for shear force it can be concluded that for building up to 6 floor blast load induced shear force is having smaller value. However for above 6 floors building i.e. for 7 floor building and 8 floor building there is tremendous increase in shear force. For the building above 8 floors shear force try to attend a constant value. Similar is case for bending moment.

Results for bending moment are shown in the table 4

Bending Moment in KN-m				
Type of building	Distance of charge 40 m			
	0.1T	**0.2T**	**0.4T**	**0.6T**
3 floors	30.9	52.6	95.12	133.5
4 floors	25.9	43.7	79.73	109.2
5 floors	24.6	37.5	68.26	92.14
6 floors	21	35.7	63.18	85.99
7 floors	60.1	95.8	160.7	216.7
8 floors	62	99	161.3	221.5
10 floors	62.5	97.9	166.5	227.2
12 floors	64.4	103	170.3	230.3

Table 5: Results for Bending Moment in KN-m

Graphical representation of above results is shown figure 7.

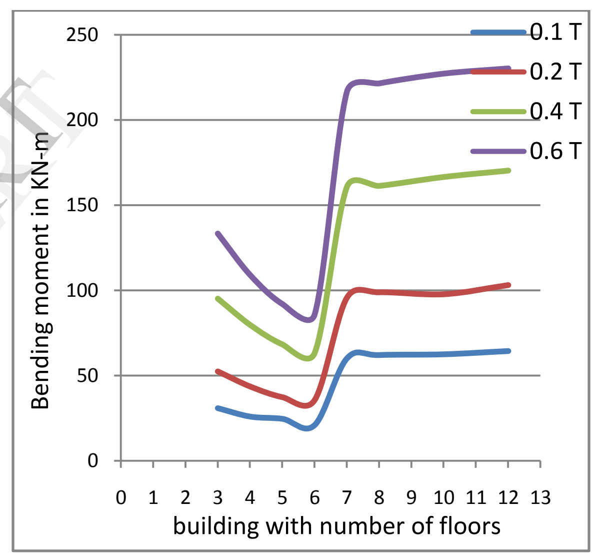


Figure 10: Bending moment variation in footing due to blast

Conclusion:

A blast wave is a high intensity wave with a very short duration. As the intensity of blast increases the positive phase duration goes on reducing. While designing foundation of building for blast resistant design height of the building is important factor. For buildings having less than 6 floor high tensile load is induced due to blast. Hence provisions to prevent uplift need to be done for foundation on exposed side whereas crushing failure due to excess compressive load need to be taken care of for columns on rear side. Shear force and bending moments is comparably less on the foundation of building less than 6 floor. For building having more than 6 floors the tensile forces reduces significantly due to self weight of the structure, and shear force and bending moment become predominant. Hence it can be concluded for that building having more than 6 floors there is less probability of overturning and crushing failure, however great care need to be taken to resist shear force and bending moment.

References:

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