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Analysis of Regular Shaped Building under Blast Loading

Mehezeen Syed[1], Pradeep Karanth[2]
[1]*M.TECH Student* (structures), [2]*Assistant Professor, Department of Civil Engineering, NMAM Institute of Technology, Nitte*

Abstract: These days the use of vehicular bombs to attack crowded areas has been a feature of campaigns by terrorist organizations around the world. Due to the threat from such extreme loading conditions, efforts have been made during the past three decades to develop methods of structural analysis and design to resist blast loads. This paper presents a comprehensive overview of the effects of explosion on buildings like building with shear wall and building with X bracing. An explanation of the nature of explosions and the mechanism of blast waves in Air Burst condition is given. A 3D model of RCC framed structures (G+6) is developed using SAP 2000 software by defining the geometric properties and material properties confirming to IS 456:2000. This paper shows that blast parameters mainly depend on Charge weight and Stand-off distance. The increase in blast load leads to increase in displacement and inter storey drift. Also from the comparison of building with and without Shear wall at the front face, the building with shear wall shows a gradual decrease in displacement along the height of the building. Whereas by optimizing the X bracing level-wise, it shows drastic decrease in displacement. However in both cases, the rate of reduction of displacement increases with the increase in height of the building.
Keywords: Blast load, Stand-off distance, Shear wall, X Bracing, Storey Displacement, Storey Drift Introduction

I. INTRODUCTION

The collapse of structures from the terrorism is a crucial part in these days. Explosion is a growing problem; prevention of this problem requires knowledge about the explosion process. The behaviour of building subjected to spontaneous loads creates dangerous effect. A significant research work has been studied for future safety. Structures are not ready to take unusual loads and it is impossible to resist, the main source for such forces are gas burst, Vehicular bomb, aircraft collision. When the building under a strong striking force undergoes complete destruction of structure, then the effect of damage can be understood by a detailed study.

Blast load is a quick release of potential energy characterized by very bright flash released as thermal radiation (flash), a part of which is combined into the air and other into the soil such as ground waves. The effect of blast explosion is in the form of shock or impact waves, which are composed of very high intensities. These waves expand outward from the source of origin to neighbouring region. As waves are expanded in the outward region, the strength of waves is reduced based on the distance i.e. as length of waves increases the effect of load decreases on the structure.

As there is increased demand of higher safety of structures due to extreme blast effects, finding out the behaviour of structural elements such as beam, column, slab, etc is much more necessary. Effects of blast loads are in the form of shock waves which are directly related to stress – wave propagation. From figure 1 blast loads is very high in amplitude for particular frequency compared to other loads such as seismic, wind, machine loads etc. hence blast load needs a special attention in the analysis process.

The effect of waves varies based on distance between the charge and structure. As the distance of charge increases, the effect of shock wave decreases and vice – versa. The effect of pressure on the structures will be from microseconds to milliseconds.

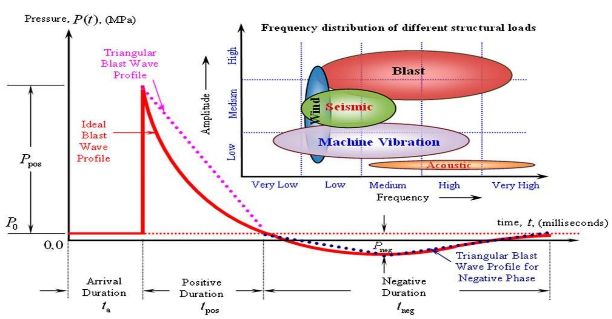

Figure 1- Blast Wave & Amplitude Frequency

When the blast or explosion occurs based on the charge weight and standoff distance, a rapid release of energy takes place which leads to blast wave or shock waves. These waves travel in air radially is termed as incident waves and those which travel along the ground are termed as reflected waves. Both these waves will travel quickly (high speed). The intensities of shock wave depend on nature of explosive material and distance.

II. LITERATURE REVIEW

Several structures have been failed due to blast loads in past decades. Several researches conducted experimental and analytical studies for understanding the behaviour of structural and analytical solution, few of them are presented below.

T Ngo, P. Mendis et, al. [1] illustrated that the terror attack inside or close-by building causes major damages to the building as well as the life of the people. Because of the danger from such risky loading conditions, so many methods had been carried out to construct a blast safe structure. The examination and design of a blast proof structure needs a complete comprehension of the explosion phenomenon and dynamic response of different structural members. In the present paper a clarification of nature of explosion and system of blast wave in free air is given. Present paper additionally introduces individual methods to estimate blast load and structural response. It is concluded that for high risk places for example public and commercial tall building, blast resistant structure should be constructed. Providing ductility also improve the building to resist the blast load.

John E. Crawford and Hyung-Jin Choi [2] In this paper they will focus on blast resistant design structure. Analytical tool is used to determine the size and location of vehicular bomb. Mainly they focused on the uncertainties with the engineering tools used for the analysis. The tools are single degree freedom models, design curves and response surfaces. To reduce the uncertainty in the design parameters like column size and strength will treated as key parameters for the design. The type of loads is included in the design process, in practices to evaluate the response of structure 100kg TNT is used and placed at the perimeter of the building. The computation results will be analysed, for knowing the actual behaviour of the building compared with high fidelity physics based modelling.

Zeynep Koccaz et al. [3] the expansion in the quantity of terrorist attacks particularly over the most recent couple of decades has demonstrated that impact of blast load on structures is genuine issue that ought to be mulled over in the outline procedure. In spite of the fact that these sorts of blasts are outstanding cases, human influenced calamities; to blast loads are in truth powerful loads should be painstakingly computed simply like seismic loads and wind loads.

The target of investigation is to reveal insight into blast safe building plan speculations, the upgrade of building security against the impact of explosives in both compositional and auxiliary outline process and the design procedures that ought to be completed. Initially, explosives and impact forms have been explained rapidly. Additionally, the general pieces of impact procedure have been acquainted with clear up the effects of explosives on structures. To have an unrivalled understanding of explosives and characteristics of impact will lead us to make us impact safe structure plan all the more capably. An essential procedure for extending the resisting limit of a structure to give security against psychological militant impact is talked about both in building and basic methodology.

Pedro F. Silva and Binggeng Lu [4] This paper presents A Series of tests conducted for assessing the blast resistant RC slabs. Estimation of explosive charge weight and standoff distance from imposed loads damage levels on structure (RC). They referred case study of the blast event on Murrah building in Oklahoma town (1995). In this, a complete failure of building occurs and minor to major catastrophic damage analyzed based on standoff distance, charge weight of explosive material. They were adopted the SDOF and FEMA methods to analyses the case. The ductile detailing of RC slabs reduces the certain level of damage. Totally, the test on slabs has demonstrated based on the displacement ductility level and residual crack width of structural member well. In this paper, the DBD (displacement-based design) methods adopted for estimation of damage level and this is accurate method of prediction of damage.

Assal T. Hussein [5] carried out the analytical method for a SDOF frame work investigation subjected to blast loading. Two sort of blast wave applied to recognise the non-linear behaviour of the building. Time history analysis is conducted which gives the basic study of the behaviour of SDOF system under blast load. Two kinds of blast wave simple and bilinear pulse is applied. Result showed the type of wave on time history analysis and computed energy. The outcome obtained from the computer program NON-SDOF clarified the impact of type of blast wave on the behaviour system.

Hrvoje Draganic and Vladimir Sigmund [6] presented a way towards deciding the blast load on the structure also give number of case of an invented structure presented to this load. The point was to get comfortable with the problem of blast load due to regularly developing terror attacks and absence of rules. The blast load for close blast was resolved and mimicked on a model building utilizing SAP2000 and loading was characterized as a record of weight after some time. It is found that the building which is exposed to far explosion requires only the sufficient ductility and for close explosion more reinforcement is required.

Manmohan Dass Goel & Vasant A.Matsagar [7] proposed that due to the fanatic activities, the buildings are presented to dangers from blast load. Lots of incidents have taken place which caused risk to life and property. Therefore the aim of this study is to present different strategies for blast load to make it less severe and to protect the structure.

Tactics to protect the structure from blast are classified into two types: strengthening the member and protection strategies. It is found that protection of the structure is less expensive when compared to the other and also it includes standoff distance from the hazard so that the blast load pressure reduces due to the distance. And they also provide a solution for places like cities where standoff distance cannot be provided. In such situation a designed blast wall can be provided to resist the blast pressure.

Jacob C. Bruhl and AmithH.Varma [8] Based on the paper, the steel plate-reinforced concrete structures used as protective system in building. In this, paper the test illustrated by placing steel reinforcement at the extreme fiber section so that the strength and stiffness increased than that of RC construction.

The analysis of SC structural member subjected to the explosion especially one-way slab. The major modifications are made for RC member to resist the blast loads, Improved in the design parameters. The containment of concrete reduces the spalling, scabbing and debris due the impact loads. The design methods adopted by the code TM 5-1300 from the military organization US. In this paper, the building is analyzed by single degree freedom system and finite element analysis. Calculation is done using UFC code and FEA by using LS-DYNA software.

Umesh Jamakhandi and Dr.S.B. Vanakudre [9] objective is to understand the blast proof buildings design theories, improvement of building security against explosive. Explosives and blast types have discussed in the beginning. The software ETABS is used to analyze the blast load and plotted a graph lateral displacement versus height of the building. It is concluded that when the charge weight is amplified, the storey drift goes on increases and as the standoff distance increases, the storey drift goes in decreases. It is found that the most optimum model is rectangular frame which shows the lowest value of story drift.

Christopher D. Eamon et al. [10] presented that different qualities of a building will impact its reaction when exposed to blast load. In this examination, the resistance of a reinforced concrete structure to the blast load was examined using an existing finite element approach. 14 different models were created to analyse, with 5 structure designed as moment resisting frame structures and 9 were designed as shear wall structures. Structures with 3,6,10 stories and 3, 4, 5 bay symmetric setups were considered. Charging weights were given depends on the building height in the range of 340-700 kg. The result shows that the parameters such as building size and shear wall placement has major role in design of blast resistant structure.

A. Insight of Literature Review

1) From the various studies it is observed that the load on the structures due to blast is evaluated from UFC code.
2) All the studies were based on the amount of TNT and its location.
3) Different types of structures are selected mainly
4) High rise structures.
5) Irregular structures.
6) Structure with bracings
7) Structure with shear wall, etc.

III. EXPLOSIVE MATERIALS

The explosive materials can be divided into three types which mainly depend on their physical state i.e. solid, liquid and gases. Usually solid type has more explosive capacity than liquid and gases type explosive. Hence, solid explosives are also called as high explosives.

Solid explosives are most widely used explosive materials in almost all cases. The explosion event requires the explosive material, usually for the explosion the solid type of material used which having high rate of detonation capacity. Trinitrotoluene is the mostly used explosive having high velocity rate of blast. It is insensitive to shock requires the ignition from the blast wave.TNT is used as standard reference point for the explosion. TNT equivalent of 1.3 would mean that 1 kg of that particular material would be equivalent to 1.3 kg of TNT.

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Table 1. Types of explosive material and its equivalent weight in TNT

Explosive	Mass specific Energy Qx (kj/kg)	TNT equivalent Qx/QTNT
Nitro-glycerine (Liquid)	6700	1.481
C4 (91% RDX)	--	1.19-1.37
HMX	5680	1.256
Semtex	5660	1250
RDX (Cyclonic)	5360	1.185
Compound B (60% RDX 40% TNT)	5190	1.148
TNT	4520	1.0
Blasting gelatin	4520	1.0
ANFO (94% ammonium nitrate, 6% fuel oil)	3932	0.870
60% nitro-glycerine dynamite	2710	0.6

IV. METHODOLOGY

A 3D model of RCC framed structures (G+6) is developed using SAP 2000 software by defining the geometric properties and material properties confirming to IS 456:2000. Dead loads and Live loads are taken from IS 875 (Part 1 and 2). The reinforced concrete frame structure consists of 3 bays in X direction and 5 bays in Y direction. The storey height was restricted to 3.2m. The overall size of the structure is (4.8 x 8.3 x 23.9) m. The grade of concrete used for slabs and beams is M20 and grade of concrete used for columns is M25.The grade of steel used for reinforcement is Fe500.

The properties of sections consists of dimensions of columns and beams; thickness of wall and slabs. The column and beam dimensions are 200mmX600mm and 200mmX450mm respectively. Further the thickness of main wall is 200mm and partition wall is 100mm. The slab thickness is 125mm and 115mm for main and sunken slab respectively. As per IS 875 part1, Dead load given is 1.5 kN/ m². And as per IS 875 part2, Live load given is 2 kN/ m². The plan of the structure is shown in Figure1 and 3-D view of building is shown in Figure2.

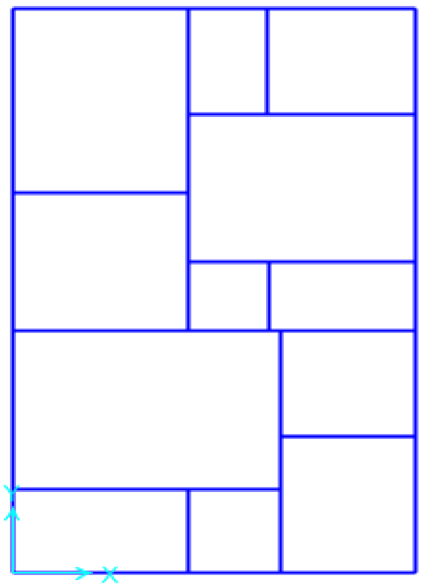

Figure 2- Plan of the Building

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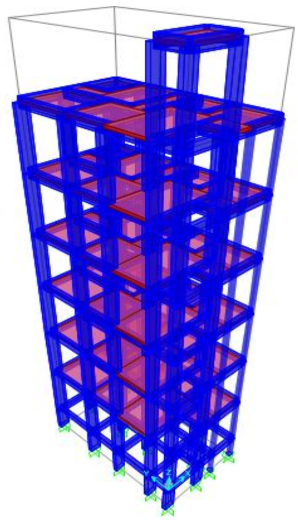

Figure 3- Rendered View of the Building

The Guidelines from UFC 3 340-02 code are used for the calculation of external Air blast load. The blast joint load values and pressure values for different charge weight of 100kg, 200kg, 300kg at varying stand-off distances of 20m and 40m are as shown in Table 2. These obtained blast load values are applied as joint load at the front side of the building as Shown in Figure 4.

Table 2. The pressure and joint load acting on the front face

Weight of Explosive (RDX)	Pressure on the front face in kN/m^2	Stand-off distance in m	Corner joint load in kN	Middle joint load in kN
100 Kg	194.98	20 m	107.93	215.85
	50.98	40m	28.22	56.44
200 kg	311.42	20m	172.38	344.75
	74.2	40m	41	82
300 kg	483.88	20m	267.8	535.66
	76.0	40m	43.06	84.13

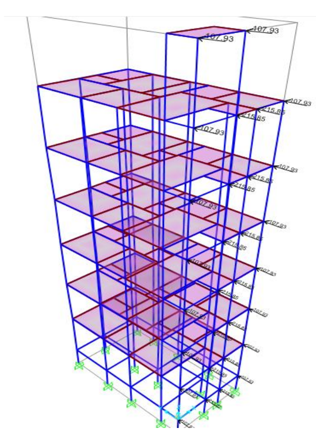

Figure 4- 100 kg RDX (118.5 TNT) blast load applied at front face of building as joint load at 20m stand-off distance**.**

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A. Strengthening Strategies

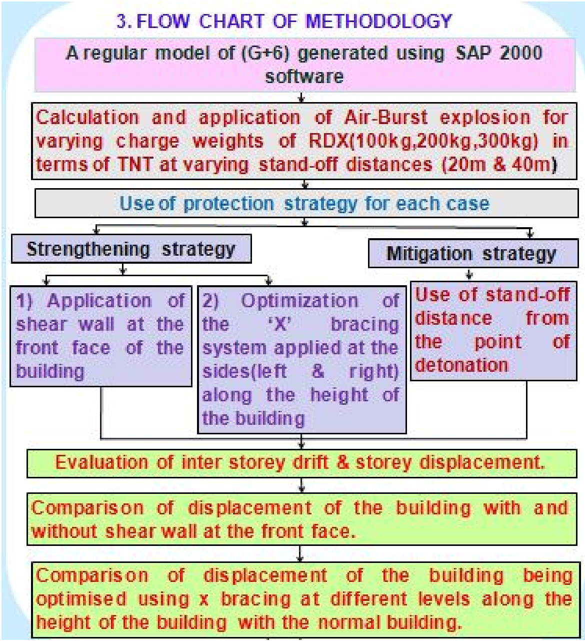

Figure 5- Flowchart of methodology

From the above flowchart it is clear that the Strengthening strategies are of two types, namely, Application of the shear wall at the front face of the building as shown in Figure 6. And Optimisation of X bracing system applied at the peripheral sides (left and right only) along the height of the building level wise as shown in Figure 7.

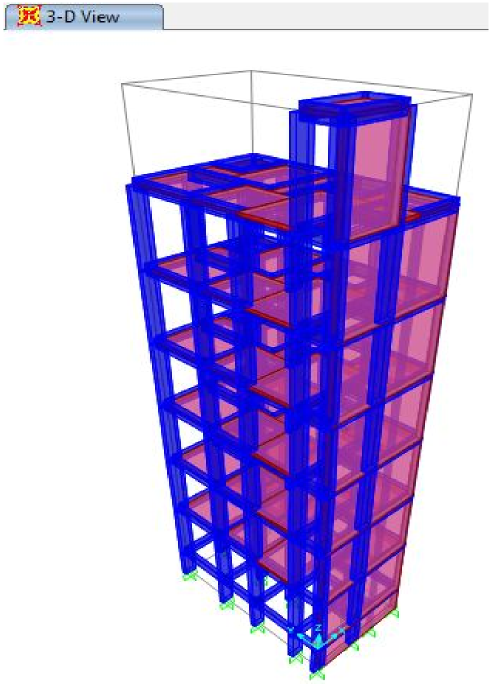

Figure 6- Shear wall of 250mm thick at the front face of the building

Shear walls give enormous strength and firmness to structures toward their direction, which altogether lessens lateral sway of the structure and in this manner decreases harm to structure. The thickness of shear wall at any part of the structure preferably is not less than 150mm as per IS: 13920:1993. Hence the thickness of shear wall length is fixed to 250mm, as in India the wall thickness will be usually 230mm.

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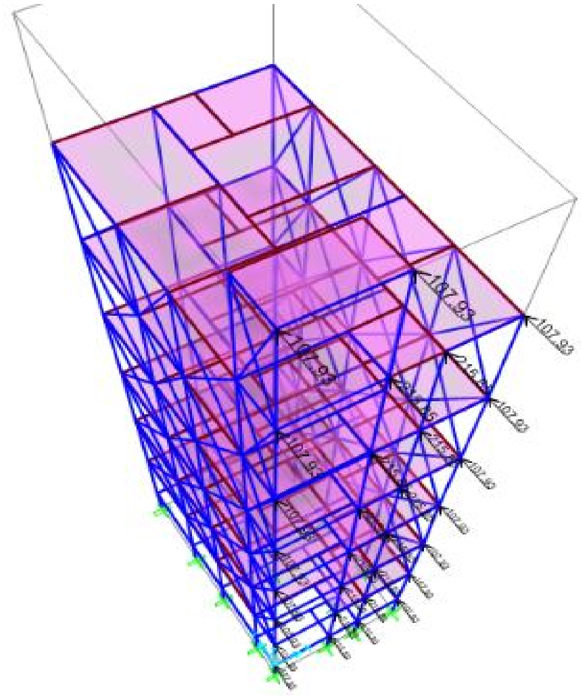


Figure 7- Bracing provided upto terrace level at left and right side of the building

In development, X propping is a framework used to strengthen building structures in which corner to corner supports intersect. X bracing can expand a structure's ability to withstand seismic movement. X propping is typically observed with two corner to corner supports put in an X formed way; these support compression and tension forces. With Different powers, one prop will be under tension while the other is being compacted. It helps make structures stand sturdier and oppose horizontal powers. X bracing can be connected to any rectangular casing structure, for example, seats and bookshelves. This method of construction maximizes the weight of the load on a structure which enables better supporting system. A channel section ISMB250 is used to resist the blast load. In this thesis, an effort is made to optimise the use of X bracing by increasing the application of the bracing system one level at a time. X bracing is applied starting from the first floor to the top.

V. RESULTS AND DISCUSSION

The determination of blast load is affected by different factors. The variation of charge weight and standoff distance are important part in the investigation of blast load. In the analysis of blast load, the effect of structure mainly varies based on use of explosive material and its capacity. The 100 kg TNT explosive material placed at 20m distance gives large dynamic load compared to placing of explosive at 40m.the behaviour of building under the blast loads are expressed as storey displacement and storey drift by using static analysis in SAP2000.

A. Storey Displacement

The building subjected to 100kg, 200kg and 300kg TNT charge weight at 20m and 40m standoff distances will gives the storey displacement or lateral displacement.

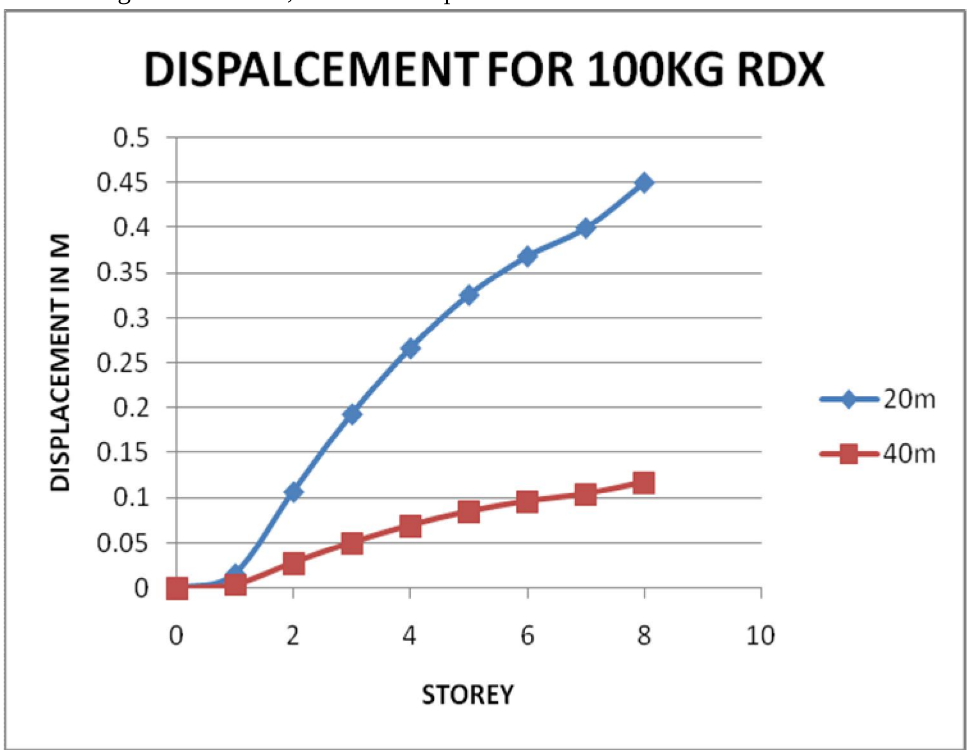
B. Storey Displacement for 100 Kg TNT at 20m and 40m Stand-off Distances.

Based on the outcome produced, the lateral displacement assists in configuration of the stability of building. The 100kg TNT placed at 20m stand-off distance gives the maximum storey displacement about 449.5mm and at 40m distance it is about 117.5mm which is about four times lesser than that of displacement at 20m distance. It is observed that the building nearer to the explosion (detonation) will undergo maximum displacement than that of building far away from the detonation point. The graph shows the displacement regular building along the height of building at different standoff distances.

Table 3. Lateral Displacement results for a charge weight 100 kg RDX at varying stand-off distances

Storey	Stand-off distance in m	
	20m	40m
0	0	0
1	0.0159	0.00415
2	0.1072	0.028
3	0.193	0.0504
4	0.2659	0.0695
5	0.325	0.0849
6	0.368	0.0962
7	0.3992	0.1044
8	0.4495	0.1175

The graph1 represents the lateral displacement for 100kg TNT placed at 20m and 40m standoff distances. It shows the displacement of the building along the height of building at different standoff distances. It is evident from the graph that as the standoff distance increases with the increase in angle of incidence, the lateral displacement decreases.



Graph 1: Lateral Displacement for a charge weight 100 kg RDX at 20m and 40m standoff distances

C. Storey Displacement for 200 Kg TNT at 20m and 40m Stand-off Distances

Table 4 shows The 200kg TNT placed at 20m standoff distance has the maximum storey displacement about 718mm and at 40m distance it is about 170.9mm.It is observed that the building nearer to the explosion (detonation) will undergo maximum displacement than that of building far away from the detonation point.

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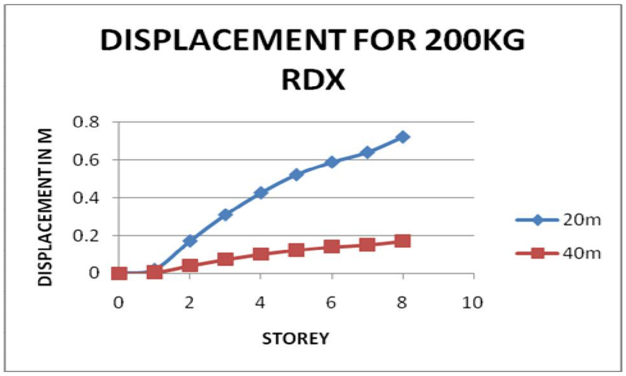
Table 4. Lateral Displacement for a charge weight 200 kg TNT at varying stand-off distances

Storey	Stand-off distance in m	
	20m	40m
0	0	0
1	0.0204	0.00565
2	0.17096	0.04072
3	0.3082	0.0737
4	0.4248	0.10117
5	0.519	0.12357
6	0.5865	0.1405
7	0.638	0.15188
8	0.718	0.1709

The graph 2 shows the lateral displacement for 200kg TNT placed at 20m and 40m standoff distances. It shows the displacement of the building along the height of building at different standoff distances. It is evident from the graph that as the standoff distance increases with the increase in angle of incidence, the lateral displacement decreases.



Graph 2: Lateral Displacement for a charge weight 200kg TNT at 20m and 40m stand-off distances

D. Storey Displacement for 300kg TNT placed at 20m and 40m Stand-off Distance.

The 300kg TNT placed at 20m stand-off distance has the maximum storey displacement about 1154.5mm and at 40m distance it is about 117.04mm which is about four times lesser than that of displacement at 20m distance. It is observed that the building nearer to the explosion will undergo maximum displacement than that of building far away from the detonation point.

Table 5. Lateral Displacement for a charge weight 300 kg TNT at varying stand-off distances

Storey	Stand-off distance in m	
	20m	40m
0	0	0
1	0.0394	0.00584
2	0.2654	0.04212
3	0.479	0.07589
4	0.6582	0.1046
5	0.8065	0.12783
6	0.9168	0.14477
7	0.9832	0.15883
8	1.1545	0.17704

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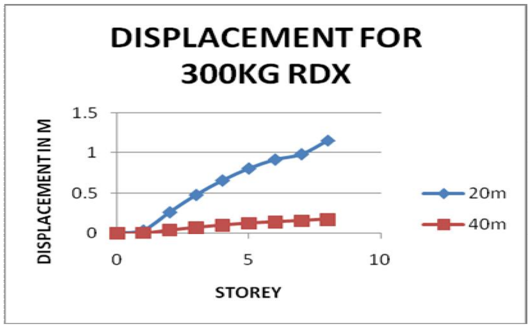
The graph 3 shows the lateral displacement for 300kg TNT placed at 20m and 40m standoff distances. It shows the displacement of the building along the height of building at different standoff distances. It is evident from the graph that as the standoff distance increases with the increase in angle of incidence, the lateral displacement decreases.



Graph 3: Lateral Displacement for a charge weight 300kg TNT at 20m and 40mstand-off distances

E. Storey Drift

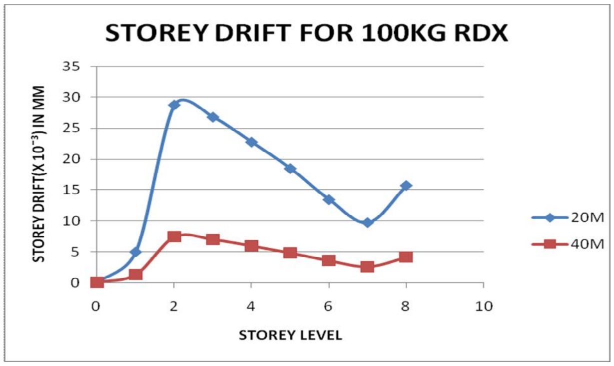
The building subjected to 100kg, 200kg and 300kg TNT charge weight at 20m and 40m stand-off distance will gives the storey drift that are tabulated.

F. Storey Drift for 100kg TNT placed at 20m and 40m Standoff Distances

Based on obtained results from the storey drift values the lateral stability of building is analysed. The 100kg placed at 20m and 40m stand-off distances gives the maximum drift about 15.71×10^{-3}mm and 4.09×10^{-3}mm respectively

Table 6. Inter storey drift for a charge weight 100kg TNT at varying stand-off distance

STOREY DRIFT(X 10^{-3}) in mm		
STOREY	Stand-off distance in m	
	20M	40M
0	0	0
1	4.97	1.29
2	28.75	7.45
3	26.8	7.0
4	22.78	5.97
5	18.47	4.81
6	13.43	3.53
7	9.75	2.56
8	15.71	4.09



Graph 4: Inter storey drift for a charge weight 100kg TNT at varying stand-off distances

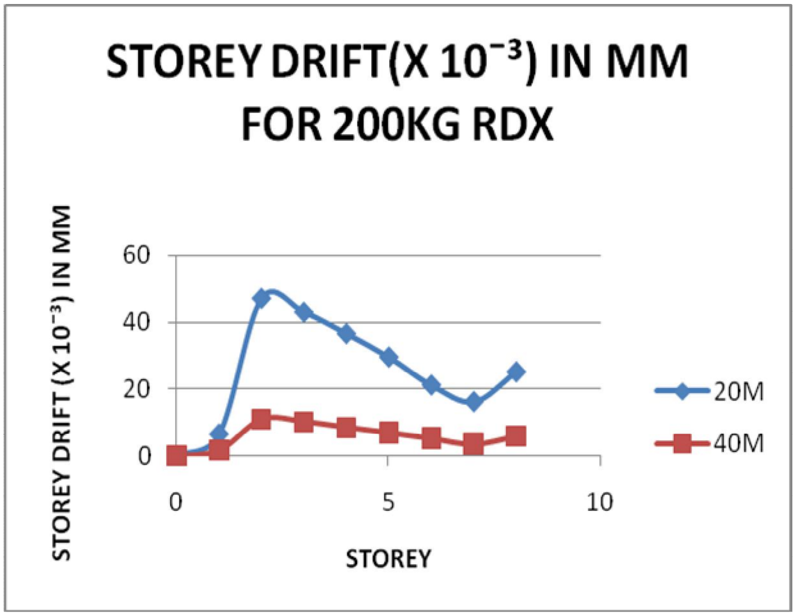
The graph 4 shows the storey drift for 100kg TNT placed at 20m and 40mstand-off distances. The structure shows the minimum drift for far away building compared to the building nearer to point of detonation. Also there is peak rise in displacement at the first floor since the Air-Burst is at a height of 10ft.

G. Storey Drift for 200kg TNT Placed At 20m and 40m Stand-Off Distances

Based on the results obtained, the storey drift gives better idea about the stability of the building. The 200kg TNT placed at 20m stand-off distance gives the maximum storey drift of about 47.05x10^{-3}mm and at 40m distance it is about 10.95x10^{-3}mm. It is observed that the building nearer explosion (detonation) will undergoes maximum displacement than for the building far away from the detonation point. The below table shows the inter-Storey drift for a charge weight of 200kg TNT at a varying Stand-off distances.

Table 7. Inter storey drift for a charge weight 200kg TNT at varying stand-off distance

STOREY DRIFT(X 10 $^{-3}$) in mm		
STOREY	Stand-off distance in m	
	20M	40M
0	0	0
1	6.375	1.768
2	47.05	10.95
3	42.88	10.3
4	36.43	8.58
5	29.43	7
6	21.09	5.29
7	16.09	3.55
8	25	5.94



Graph 5: Inter storey drift for a charge weight 200kg TNT at varying stand-off distances

The graph 5 shows the storey drift for 200kg TNT placed at 20m and 40mstand-off distances. For 200kg, TNT placed at 20m and 40mstand-off distance gives the 47.05x10^{-3}mm and 10.95x10^{-3}mm respectively as maximum storey drift. It is observed that the building nearer explosion (detonation) will undergoes maximum displacement than for the building far away from the detonation point.

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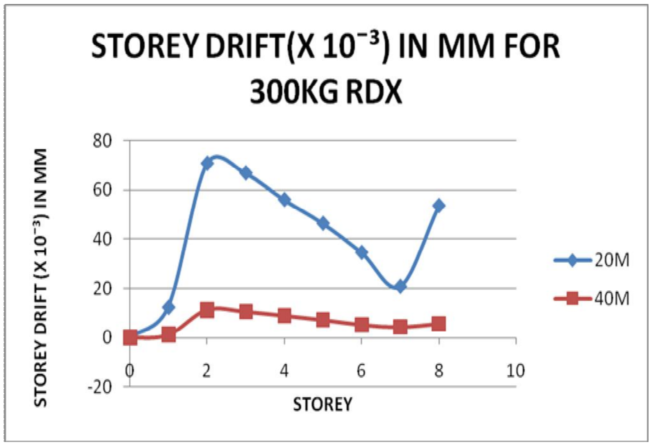
H. Storey Drift for 300kg TNT Placed At 20m and 40m Stand-Off Distances

It is observed that the building nearer explosion (detonation) will undergo maximum displacement than building far away from the detonation point. The graph shows the displacement of a regular normal building at different standoff distances to control the lateral displacement. The 300kg TNT placed at 20m stand-off distance gives the maximum storey drift about 70.62×10^{-3}mm and at 40m stand-off distance it is about 11.33×10^{-3}mm.

Table 8. Inter storey drift for a charge weight 300kg TNT at varying stand-off distance

STOREY DRIFT(X 10^{-3}) in mm		
	Stand-off distance in m	
STOREY	20M	40M
0	0	0
1	12.31	1.25
2	70.625	11.33
3	66.75	10.56
4	56	8.97
5	46.34	7.25
6	34.47	5.29
7	20.75	4.39
8	53.53	5.69



Graph 6: Inter storey drift for a charge weight 300kg TNT at varying stand-off distances

The graph 7.6 shows the storey drift for 300kg TNT placed at 20m and 40m for a regular normal building. The graph clearly indicates that the inter-storey drift reduces drastically with the increase in the stand-off distance. And also there is an absence of peak drift at 40m stand-off distance which implies that there will be no further drift beyond 40m stand-off distance.

I. Comparative Storey Displacement of the Building with and Without Shear Wall at the Front Face

The results show the Storey Displacement of a building with and without shear wall for different Charge weights and also varying Stand-off distances.

J. Comparative Study of Storey Displacement for 100kg TNT Burst In Air In Front of the Building with and without Shear Wall

From the below table, we can conclude that the building with shear wall displaces comparatively lesser the building without shear wall. At the top floor where the displacement id maximum for another Air-burst of 100kg RDX, it is evident that the displacement is reduced by almost 1000mm.

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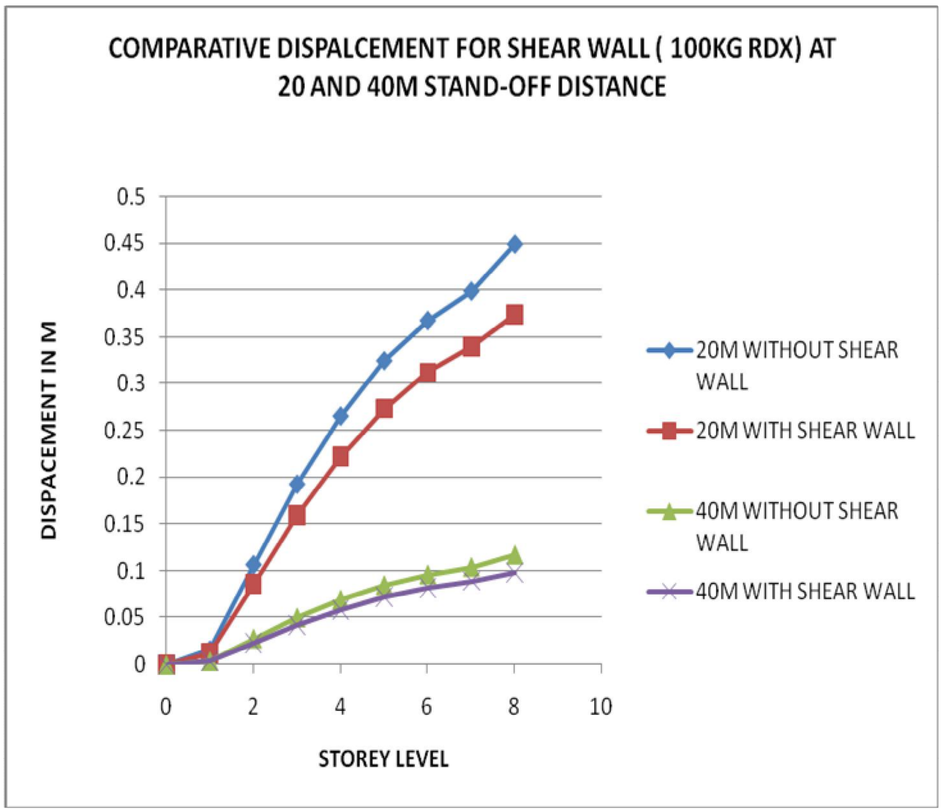
Table 9. Storey Displacement for a charge weight of 100kg TNT at varying stand-off distance

DISPLACEMENT IN 'm'				
WITHOUT SHEAR WALL			WITH SHEAR WALL	
Stand-off distances in 'm'				
Storey	20m	40m	20m	40m
0	0	0	0	0
1	0.0159	0.00415	0.0126	0.004
2	0.1072	0.028	0.0864	0.0227
3	0.193	0.0504	0.1597	0.0417
4	0.2659	0.0695	0.2223	0.0581
5	0.325	0.0849	0.2732	0.0714
6	0.368	0.0962	0.3118	0.0815
7	0.3992	0.1044	0.3396	0.0888
8	0.4495	0.1175	0.3738	0.0977



Graph 7: Storey Displacement for a charge weight 100kg TNT at varying stand-off distances

From the above graph it is evident that the displacement of the building nearer to the point of detonation and without shear wall is comparatively greater.

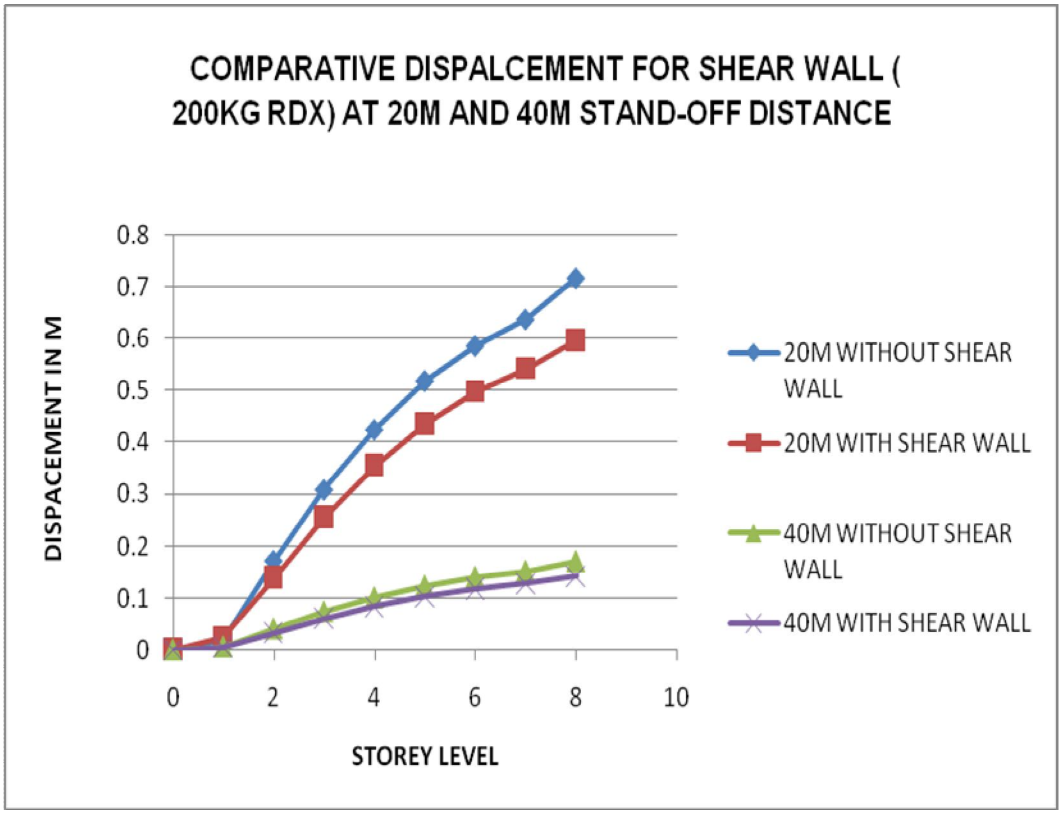
K. Comparative Study of Storey Displacement for 200kg RDX Burst In Air In Front Of the Building with and Without Shear Wall

From the results shown in tabular column below, the maximum storey displacement of 718mm at the top floor is shown for the building nearest to the detonation point and without shear wall. No doubt that the most important means of increasing the resistance of the frames was to increase the stiffness of the building. The use of shear wall has considerably reduced the storey displacement.

Table 10. Storey Displacement for a charge weight of 200kg TNT at varying stand-off distance

DISPLACEMENT IN 'm'				
	WITHOUT SHEAR WALL		WITH SHEAR WALL	
Stand-off distances in 'm'				
Storey	20m	40m	20m	40m
0	0	0	0	0
1	0.0204	0.00565	0.0245	0.0058
2	0.17096	0.04072	0.1384	0.033
3	0.3082	0.0737	0.255	0.0607
4	0.4248	0.10117	0.3551	0.0845
5	0.519	0.12357	0.4364	0.1039
6	0.5865	0.1405	0.4981	0.1186
7	0.638	0.1518	0.5425	0.1292
8	0.718	0.1709	0.597	0.1421

The graph shows that, the use of shear wall helps in gradual decrease of storey displacement in both the case of stand-off distances. However the storey displacement of the building with the shear wall at front face and closer to the point of detonation shows larger displacement than the far-off building.



Graph 8: Storey Displacement for a charge weight 200kg TNT at varying stand-off distances

L. Comparative Study of Storey Displacement for 300kg RDX Burst In Air In Front Of the Building with and Without Shear Wall

From the table shown below, we can see that the Storey displacement of a building exposed to 300kg RDX is greater than the building exposed to 100kg and 200kg RDX. Also, the rate of reduction of displacement along the height increases gradually with the increase in storey height.

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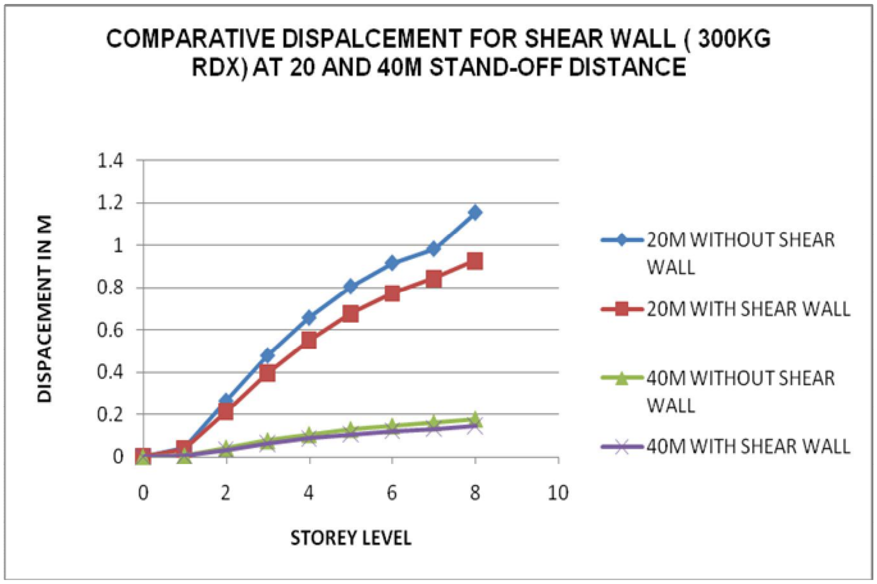
Table 11. Storey Displacement for a charge weight of 300kg TNT at varying stand-off distance

DISPLACEMENT IN 'm'				
	WITHOUT SHEAR WALL		WITH SHEAR WALL	
	Stand-off distances in 'm'			
Storey	20m	40m	20m	40m
0	0	0	0	0
1	0.0394	0.00584	0.0381	0.006
2	0.2654	0.04212	0.215	0.0341
3	0.479	0.07589	0.3961	0.0628
4	0.6582	0.1046	0.5516	0.0874
5	0.8065	0.12783	0.678	0.1075
6	0.9168	0.14477	0.7738	0.1227
7	0.9832	0.15883	0.8428	0.1336
8	1.1545	0.17704	0.9276	0.1471



Graph 9: Storey Displacement for a charge weight 300kg TNT at varying stand-off distances

The Storey displacement is also dependant on the charge weight and distance from it. The presence of shear wall at the front face reduces the storey displacement to a greater extent.

M. Comparative Storey Displacement Of The Building With Optimization Of X Bracing Level-Wise

The results show the Storey Displacement of a building which is optimised using X bracing level-wise for different Charge weights and also varying Stand-off distances.

N. Storey Displacement Of The Building Which Is Optimized Using X Bracing Level-Wise And 20m Away From An Air-Burst Of 100kg RDX

The table 12 clearly shows the application of the bracing from level1 to level5 for a G+6 building. We can observe that the displacement of the building without bracing is greater. Also, the displacement at the top floor has reduced around 300mm when the bracing is provided throughout the building height.

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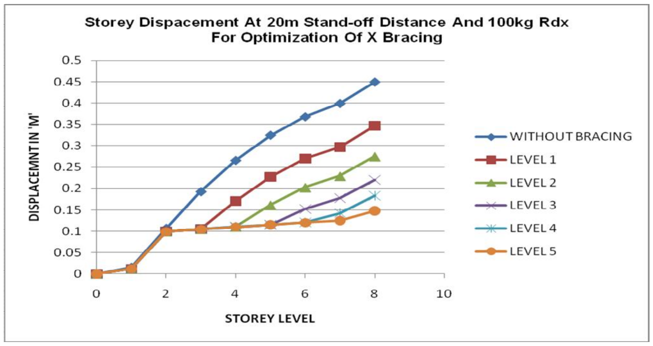
Table 12. Storey Displacement At 20m Stand-off Distance And 100kg RDX for Optimization of X Bracing

DISPLACEMENT IN 'M'						
STOREY LEVEL	WITHOUT BRACING	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
0	0	0	0	0	0	0
1	0.0159	0.0125	0.0125	0.0126	0.0125	0.0124
2	0.1072	0.0994	0.0994	0.0992	0.0992	0.0992
3	0.193	0.1055	0.105	0.1049	0.1049	0.1049
4	0.2659	0.1704	0.1106	0.1103	0.1103	0.1103
5	0.325	0.2273	0.1615	0.1156	0.1155	0.1156
6	0.368	0.27	0.2027	0.1522	0.1205	0.1206
7	0.3992	0.2966	0.2294	0.1778	0.1427	0.1251
8	0.4495	0.3464	0.2752	0.2207	0.1832	0.1483



Graph 10: Storey Displacement At 20m Stand-off Distance And 100kg RDX for Optimization of X Bracing

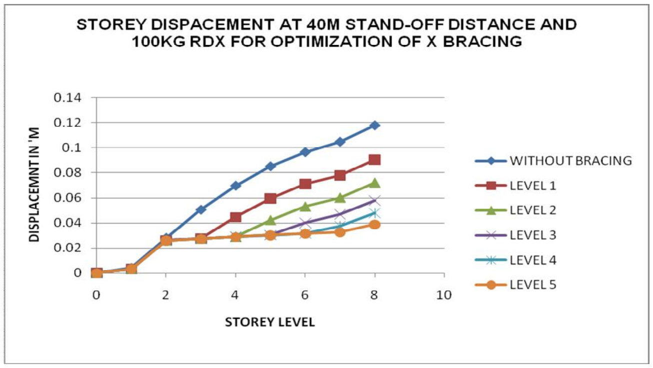
The graph10 clearly shows that, as the level of X bracing increases, the displacement decreases. Also the displacement at initial storeys decreases gradually.

O. Storey Displacement Of The Building Which Is Optimized Using X Bracing Level-Wise And 40m Away From An Air-Burst Of100kg RDX

From the results, it is evident that the storey displacement has drastically reduced when compared the building nearer to the Air-burst. Besides the reduction rate is almost four times greater. The building at level4 is optimised completely using X bracing and it satisfies the IS code 456 criteria of maximum allowable storey displacement of H/500, that is 47.8mm.

Table 13. Storey Displacement At 40m Stand-off Distance And 100kg RDX for Optimization of X Bracing

DISPLACEMENT IN 'M'						
STOREY LEVEL	WITHOUT BRACING	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
0	0	0	0	0	0	0
1	0.00415	0.0033	0.0033	0.0033	0.0033	0.0033
2	0.028	0.0261	0.026	0.026	0.0259	0.0259
3	0.0504	0.0276	0.0275	0.0274	0.0274	0.0274
4	0.0695	0.0446	0.0289	0.0288	0.0288	0.0288
5	0.0849	0.0594	0.0422	0.0302	0.0302	0.0302
6	0.0962	0.0709	0.053	0.0398	0.0315	0.0315
7	0.1044	0.078	0.0601	0.0465	0.0375	0.0327
8	0.1175	0.0906	0.072	0.0577	0.0479	0.0388



Graph 11: Storey Displacement At 40m Stand-off Distance And 100kg RDX for Optimization of X Bracing

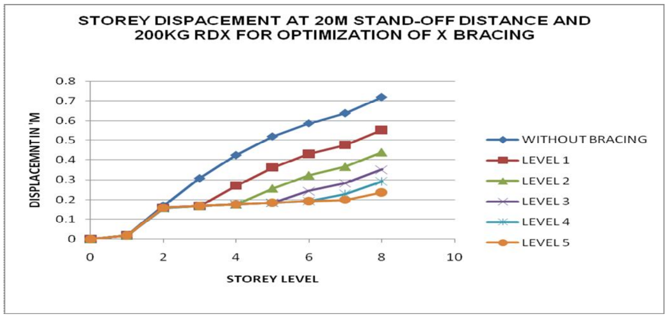
The graph11 shows a characteristic decease in displacement irrespective of the distance and Charge weight. As the level of optimisation increases the rate of reduction of displacement increases.

P. Storey Displacement Of The Building Which Is Optimized Using X Bracing Level-Wise And 20m Away From An Air-Burst Of 200kg RDX

Based on the results obtained from the lateral displacement, it gives an idea about the stability of the building. The 200kg TNT places at 20m Stand-off distance gives the maximum storey displacement about 718mm for a normal regular building , Whereas for the building with bracing up to level1 is 553.2mm, up to level2 is 439.6mm, up to level3 is 352.6mm, up to level4 is 292.6mm and up to level5 is 236.9mm. It is observed that the level of bracing system increases, the storey displacement decreases.

Table 14. Storey Displacement At 20m Stand-off Distance And 200kg RDX for Optimization of X Bracing

DISPLACEMENT IN ' M '						
STOREY LEVEL	WITHOUT BRACING	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
0	0	0	0	0	0	0
1	0.0204	0.02	0.0199	0.0199	0.0199	0.0199
2	0.17096	0.1591	0.1588	0.1586	0.1584	0.1584
3	0.3082	0.1685	0.1678	0.1676	0.1675	0.1675
4	0.4248	0.2721	0.1766	0.1761	0.1761	0.1762
5	0.519	0.363	0.258	0.1847	0.1845	0.1846
6	0.5865	0.4313	0.3238	0.2439	0.1925	0.1926
7	0.638	0.4765	0.3668	0.2839	0.228	0.1997
8	0.718	0.5532	0.4396	0.3526	0.2926	0.2369



Graph 12: Storey Displacement At 20m Stand-off Distance And 200kg RDX for Optimization of X Bracing

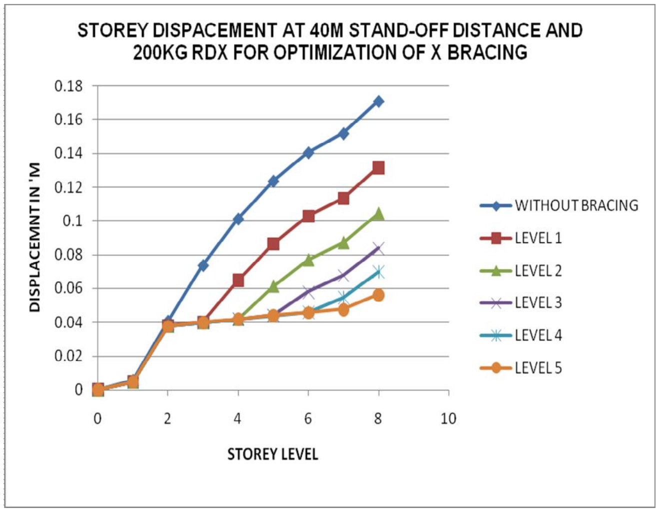
The graph shows a lateral displacement for charge weight of 200kg TNT placed at 20m Standoff distance. It is evident that, the bracing system is successful in the reduction of storey displacement.

Q. Storey Displacement Of The Building Which Is Optimized Using X Bracing Level-Wise And 40m Away From An Air-Burst Of 200kg RDX

Table () shows that 200kg TNT placed at 40m Stand-off distance gives maximum Storey displacement of about 170.9mm at the top floor without the bracing system. The top floor displacement after level5 bracing system is 56.4mm which is 100mm less than that of the building without bracing system.

Table 15. Storey Displacement At 40m Stand-off Distance And 200kg RDX for Optimization of X Bracing

DISPLACEMENT IN ' M '						
STOREY LEVEL	WITHOUT BRACING	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
0	0	0	0	0	0	0
1	0.00565	0.0048	0.0047	0.0047	0.0047	0.0047
2	0.04072	0.0379	0.0378	0.0378	0.0377	0.0377
3	0.0737	0.0401	0.0399	0.0399	0.0399	0.0399
4	0.10117	0.0648	0.042	0.0419	0.0419	0.0419
5	0.12357	0.0864	0.0614	0.044	0.0439	0.044
6	0.1405	0.1027	0.0771	0.0579	0.0458	0.0458
7	0.15188	0.1135	0.0873	0.0676	0.0543	0.0476
8	0.1709	0.1317	0.1046	0.0839	0.0697	0.0564



Graph 13: Storey Displacement At 40m Stand-off Distance And 200kg RDX for Optimization of X Bracing

The graph shows the lateral displacement for charge weight of 200kg TNT placed at 40m stand-off distance. The gradual decrease of Storey Displacement is the characteristic graph behaviour due to the optimisation of X bracing level-wise. However the rate of reduction in the lateral displacement increases gradually with the increase in the Storey height and the level of application of the X bracing.

VI. CONCLUSION

Based on the outcome obtained from the storey displacement and storey drift values it can be concluded that the displacement and drift values should be within the permissible limits. Otherwise, the structure will be in critical stage that means the structure leads to damage or collapse. Thus the structure should satisfy the IS code provision for displacement and drift.

The allowable maximum lateral displacement is 47.8mm (i.e. H/500) as per the Indian code IS-1893-2016. It is such that the lateral displacement of normal building (without Shear wall and bracing) with charge weight of 100kg, 200kg and 300kg RDX in terms of TNT at 20m and 40m stand-off distances are not satisfying the codal provision.

The allowable maximum inter storey drift is 12.8mm (i.e. 0.004x h)as per the Indian code IS-1893-2016. It is such that the inter storey drift of normal building (without Shear wall and bracing) with charge weight of 100kg, 200kg and 300kg RDX in terms of TNT at 20m and 40m stand-off distances stands satisfactory to the codal provision.

Results show that blast parameters mainly depends on Charge weight and Stand-off distance. The increase in blast load leads to increase in displacement and inter storey drift. Also from the comparison of building with and without Shear wall at the front face, the building with shear wall shows a gradual decrease in displacement along the height of the building. Whereas by optimizing the X bracing level-wise, it shows drastic decrease in displacement. However in both cases, the rate of reduction of displacement increases with the increase in height of the building.

From all the three models we can conclude that the reduction of lateral displacement at the top storey in all three models is about 4times the normal regular building without shear wall or X bracing. The maximum displacement value at level four optimization of X bracing system and at 40m Stand-off distance is 47.6mm. Hence the optimization of X bracing is successful and completely satisfies the IS code criteria of maximum allowable displacement of H/500 i.e. 47.8mm. The amplification of the blast load leads to increase in displacement and inter storey drift. Therefore, blast parameters mainly depend upon the charge weight and stand- off distances. As the angle of incidence increases, the effect of blast load on the structure decreases. Furthermore, as the charge weight increases and the standoff distance decreases, the velocity of blast wave and also velocity of sound increases.

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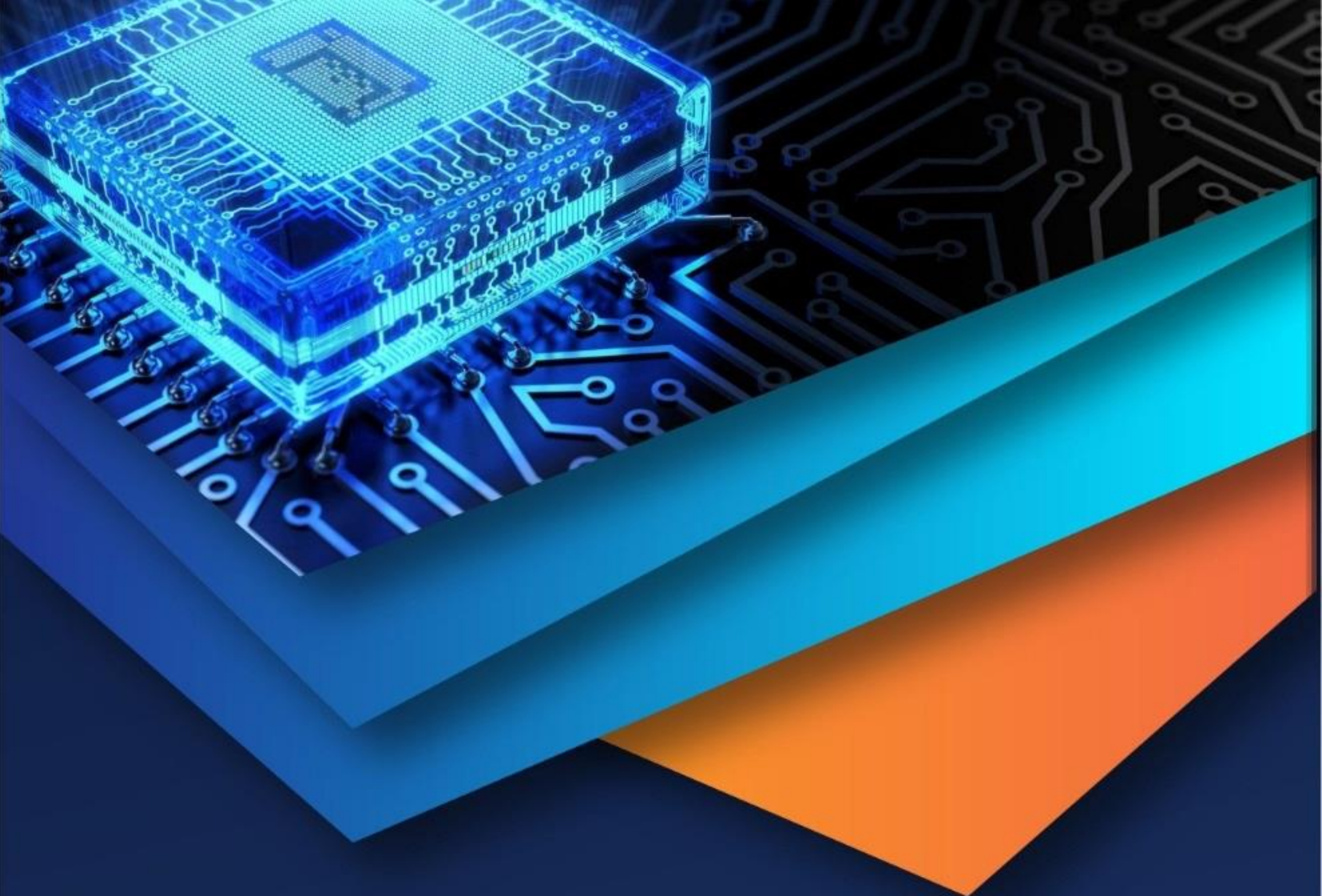

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