Impact Resistant Design of Overhead Protection Structure and BlastProof Chamber

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Abstract:
The objective of this study is to shed light on blast proof chamber design theories. The general aspects of explosion process have been presented to clarify the effects of explosives on chamber. The main aim of this work is to compare the responses of the structure having shear wall and the structure having braces. Thus, analyzing which structure is more blast resistant. Blast loads of explosives weighing 150kg and 250kg is subjected on both the models at distances 25m & 50m. Responses of both the models are observed. Overhead protection (OHP) structures are used by major oil operators and government agencies in terrorist affected areas to protect facilities housing their personnel such as office facilities and dining facilities. Structural design of OHP structures is presented in this paper. The OHP structure consists of two layers: a pre-detonation layer and a shielding layer. The pre-detonation layer consists of plywood supported by steel beams, and this will cause the ordnance to explode upon impact. The shielding layer underneath consists of steel plates and sand bags supported by steel frames. The sand bags are intended to stop the fragmentation of the mortars or rockets while the steel plates and the supporting structural frames will resist the blast and impact loads. Recent terrorist bomb attacks on buildings have resulted in increased interest in the protection of key buildings. Various research programs have provided improved design and analysis techniques as well as new mitigation methods. Advanced finite element methods provide the best analytical results because they can take into account the time varying load, dynamic structural response, non-liner material properties, and the non-linear interaction of various response modes (e.g., shear and flexure). These methods require not only time but also specialized expertise to obtain good results. They are therefore generally unpractical for typical blast design problems. Simplified methods can provide reasonable approximations that are adequate for design. A variety of types of simplified models exist. Typical models include single or multi-degree-of-freedom, pressure-impulse (P-I) diagrams, and response surfaces developed from finite element analyses. This paper describes some recently developed simplified models and associated research.

Keywords: Blast resistant design, blast waves, explosive effects.

I. INTRODUCTION

The increase in the number of terrorist attacks especially in the last few years has shown that the effect of blast loads on chamber is a serious matter that should be taken into consideration in the design process. Although these kinds of attacks are exceptional cases, man-made disasters; blast loads are in fact dynamics loads that need to be carefully calculated just like earthquake and wind loads. The objective of this study is to shed light on blast resistant building design theories, the enhancement of building security against the effect of explosivesin both architecture and structural design process and the design techniques that should be carried out. Firstly explosive and explosion types have been explained briefly. In addition the general aspects of explosion process have been presented to clarify the effect of explosions will enable us to make blast resistant building design much more efficiently. Essential techniques for increasing the capacity of a building to provide protection against explosives and characteristics of explosions will enable us to make blasé resistant building design much more efficiently. Essential techniques for increasing the capacity of a chamber to provide against explosive effects is discussed both with an architectural and structural approach. Damage to the assets, loss of life and social panic are factors that have to be minimized if the threat of terrorist action cannot be stopped. Designing the structures to be fully blast resistant is not a realistic and economical option, however current engineering and architectural knowledge can enhance the new and existing buildings to mitigate the effects of an explosion.

Objective of the Blast Design

The primary objectives for providing blast resistant design for buildings are:

Personal safety
Controlled shutdown
Financial consideration

Blast resistant design should provide a level of safety for persons in the chamber that is no less than that for persons outside the chambers in the event of an explosion. Evidence from past incidents has shown that many of the fatalities and serious injuries were due to collapse of chambers onto the persons inside the building. This objectives is to reduce the probability that the building itself becomes a hazard in an explosion. Preventing cascading events due to loss of control of process units not involved in the event is another objective of blast resistant design. An incident in one unit should not affect the continued safe operation or orderly shutdown of other units. Preventing or minimizing financial losses is another objective of blast resistant design. Buildings containing business information critical or essential equipment, expensive and long lead time equipment which if destroyed, would constitute significant interruption or financial loss to the owner should be protected.

II. LITERATURE REVIEW

A significant amount of research works is carried out by various investigators on various aspects of blast resistant building. Here some of papers are discussed in brief.

Koccaz Z. (2004) Blast Resistant Building Design, Turkey. The increase in the number of terrorist attacks especially in the last few years has shown that the effect of blast loads on buildings is a serious matter that should be taken into consideration in the design process. Although these kinds of attacks are exceptional cases, man-made disasters; blast loads are in fact dynamic loads that need to be carefully calculated just like earthquake and wind loads. The objective of this study is to shed light on blast resistant building design theories, the enhancement of building security against the effects of explosives in both architectural and structural design process and the design techniques that should be carried out. Firstly, explosives and explosion types have been explained briefly. In addition, the general aspects of explosion process have been presented to clarify the effects of explosives on buildings. To have a better understanding of explosives and characteristics of explosions will enable us to make blast resistant building design much more efficiently. Essential techniques for increasing the capacity of a building to provide protection against explosive effects is discussed both with an architectural and structural approach.

Mir M. Ali (2002) investigated several issues of terrorist proof building. He concluded design recommendation for RCC design as per TM-5-1300; as per which concrete cover on both side of member is effective in resisting blast effect, even though concrete crushed, but should be intact with steel to prevent overall collapse of the structure. Similarly, the strength of concrete should be more than 400 psi (28MPa), steel of grade 60, ASTM A should be used, size of aggregate should be limited to 1 inch (25.4mm), slab reinforcement should be in both direction, and reinforcement should be continuous in any direction. In his work, he also included case study in well- known explosion, viz. as Murrah Federal Building, Oklahama city, USA, 1996. Federal Emergency Management Agency (FEMA) investigated the incident and emphasized that transfer girder should be avoided in lower floor, where in the uilding a third storey transfer girder was supporting nine columns above and three columns below, which causes one half of the building to collapse. There was also ordinary moment resisting frame, and if special moment resisting frame was being used, 50 to 80% loss could be reduced. Secondly, in Missile attack during Gulf war, Riyadh, Saudi Arab, Amjad examined the structural responses of building during the attack, and the structure mainly affected were two to five storey RC frame. The buildings were designed for normal and wind loading, and the damage to the buildings was similar to those caused by earthquake. He studied about blast loading, standoff distance, incident and reflected pressure. And also explosion in Air force base, Dhahran, Saudi Arab. He also summarized the results of current research carried on concrete slab, subjected to high dynamic loading; and found that dynamic ultimate load capacity is 22-27% higher than the ultimate static load capacity. He also examined the effect of spalling.

Amol B. Unde, Dr. S. C. Potnis (2013) studies effect of TNT at various distances on a column foundation with different charge weight. Blast parameters like scaled distance, peak overpressure, reflected over pressure, positive phase duration, mech number etc. are determined as per IS 4991 for charge weight of 0.1 tonne, 0.2 tonne, 0.4 tonne and 0.6 tonne at distance of 30m, 35m, 1nd 40m.model of 12 storey is analysed using STAAD Pro. Blast is assumed to occur 1.5m above ground surface. Loads are assumed to act like point load at beam-column junction on the front face of the building. Graphs are obtained toshow the variation of pressure with floor level for all the charge load and standoff distance. The study shows as intensity of blast loading increases; positive phase duration goes on decreasing. Height of building is an important factor of blast resistant design. Building having floors less than 6; tensile load induces due to blast effect and shear force and bending moment is comparatively less. Building having floors more than 6, has less probability of failure by overturning and crushing, but need to resist greater bending moment and shear force.

Jayashree S. M. et. Al. (2013) investigates the dynamic behavior of three storey frame of Reinforced Cement Concrete and Slurry Infiltrated Fibre Reinforced Concrete (SIFCON) subjected toblast loading and made attempt to use SIFCON in place of RCC. Properties of SIFCON and RCC are derived and comparisons of dynamic characteristics like displacement and fundamental frequency are made. Space frames are developed and analysed using SAP 2000. Result shows use of SIFCON frame reduces about 25-30% less than RCC. The fundamental frequency of SIFCON is 30% more than RCC; strength and stiffness of SIFCON is also more than RCC. Results also shows that SIFCON has higher energy absorption capacity, higher strength and highly ductile than RCC.

Osman Shallan, Atef Eraky et. Al. (2014) investigates the effect of blast loading on two storey building with different aspect ratio with two different locations (skew and symmetric position).Finite element models were developed and analysed using AYTODYN. Variation of reflected over-pressure and temperature with time at mid height of middle and corner columns are observed at various standoff distances. Results shows reflected overpressure, temperature and displacement decreases with increase in stand-off distance. Blast loading within stand-off distance 1.5m causes total failure of columns at the front face of the building and at distance 1.6m, there is fragment of failure. There is no variation of displacement of building with variation of aspect ratio.

B. Murali Krishna, Dr. V. Sowjanya Vani(2015) analysed a (G+14) storey tall building is done of which storey height is 4m, a totaling of 52m high; which explores non-linear dynamic response of 2-D building. Various parameters like scaled ground distance, peak positive incident pressure, reflected pressure, shock front velocities are calculated. Loads are determined analytically by pressure time history analysis; and analysed by TM-5 1300. Graphs of peak impulsive pressure VS time are obtained for each storey. Result shows that distribution of reflected pressure decreases with height.

Demin George, Varnitha M.S. (2016) analysed a 2-storied building is done using ETAB. Here 4 cases are considered with various amount of explosive and standoff distances.. Also 4 models are considered normal frame, normal frame with increased cross section of beam and column, normal frame with addition of shear wall and X-type of bracing are considered. Load calculation are done as per IS-4991-1968, pressure onbuilding, load on front face joint, roof and side wall are determined. Model with shear wall and X-type bracing will result in 95% an 80 % reduction in maximum storey displacement and maximum story drift respectively. Increasing the size of beam and column will also improve resistance, but due to serviceability problem of huge cross section; it is not feasibility. Thus shear wall found is more economical and convenient too.

Mr. Bhor Amol.S, Prof. Salunkhe H.H (2016) makes a detail discussion of blast loading and their effects are made. Methodologies for protective design of building are discussed to minimise the effect of blast, to prevent overall collapse of the building, to protect life and assets, to provide shelter during the event of explosion, to enable rescue and effort to repair to be performed after the event and also planning and layout, structural form and internal layout, bomb shelter area are described to mitigate the effect of blast. Risk involved during theevent of blast; protective measures to manage risk like enhanced perimeter security, perimeter wall, vehicle barriers and inspection, security personnel, increased standoff, facility design, blast and impact resistant glazing, strengthened perimeter columns and walls, enhanced structural stability measures etc. And risk reduction processes are discussed in brief.

M. Meghanadh, T. Reshma (2017) studied effect of blast loads on 5 storey R.C.C building. Effect of 100kg Tri nitro toluene (TNT) blast source which is at 40m away from the building is considered. Blast loading and side on over pressures are calculated using IS:4991-1968. Using force time history analysis of structure is carried out using STAAD Pro. Maximum displacement, velocity and its variation with time is determined.

The natural frequency of
The building does not match with any mode shape frequency thus the building safe from the view point of resonance effect.

Gautham T N, Dr. M N Hegde (2017) investigates the effect of blast loading standoff distance which is required to analyse the building. Blast loading is required to understand the occurrence and analyse response of structural members; for which some steps are required to follow like, judging threats, computation of blast induced loadings, choosing suitable structural system and behaviour of building subjected to blast loading. In the paper analysis of a G+5 building is made, here loadings are calculated as per IS4991-1968. 16 different cases are considered and analysed using ETABS. For various amount of charge weights and standoff distances, corresponding front face pressure, side face pressure and maximum joint displacement of top storey of the building are determined. Graphs are obtained for front face pressure VS standoff distance; side face pressure VS standoff distance; maximum joint displacement VS standoff distance and also numbers of beams or columns failed to meet specified capacity VS standoff distance.

P. S. Ramesh, Dr. Devraj et. al. (2017) investigates the performance of G+4 RCC building subjected to explosive (RDX) of 100Kg, analysed by ETAB 2015 and for various standoff distance using UFC 3-340-02, positive phase parameters of explosive are obtained. He studied the significance of standoff distance. Responses are determined in terms of drift, displacement, and force in beams and columns. The structure is found to be safe at standoff distance of 80m. Loads produced by explosive, and interaction of blast wave with structure is discussed. Graphs of pressure VS standoff distance, drift VS storey, displacement VS storey, axial load VS storey, SF VS storey, BM VS storey are obtained.

Qureshi Rizwan et.al. (2017) studies the response of structure of structure subjected to blast loading having shear wall (150mm) and steel bracing. A high rise building of 20 storied is considered of storey height 3m each. For all the cases graphs are obtained storey-wise for displacement and drift for both the models and concluded that responses of a structure depends on blast loading and standoff distance. With increase in blast loading and decrease in standoff distance, displacement and storey drift increases. Shear wall effectively reduces the response of structure than steel bracing and is found to be more effective.

Types of Explosion
Mainly there are two types of explosions

Unconfined Explosions
Unconfined explosion can occur as an air-burst or a surface burst. In an air burst

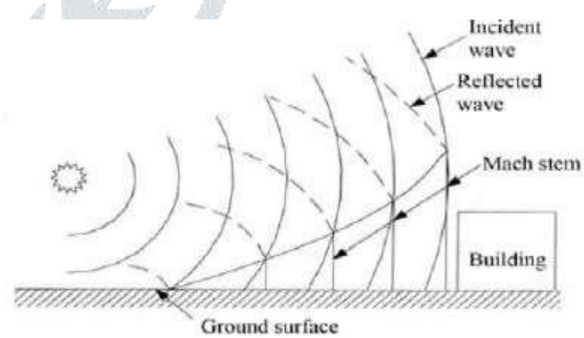

Figure.1. Air burst with ground reflections

Explosion the detonation of the high explosive occurs above the ground level and intermediate amplification of the wave caused by ground reflections occurs prior to the arrival of the initial blast wave at a building shown in above fig 1. As the shock wave continues to propagate outwards along the ground surface, a front commonly called a mach stem is formed by the interaction of the initial wave and the reflected wave. However a surface burst explosion occurs when the detonation occurs close to or on the ground surface. The initial shock wave is reflected and amplified by the ground surface to produce a reflected wave. Fig 2 shown below unlike the air burst, the reflected wave merges with the incident wave at the point of detonation and forms a single wave. In the majority of cases, terrorist activity occurs in built-up areas of cities, where devices are placed on or very near the ground surface.

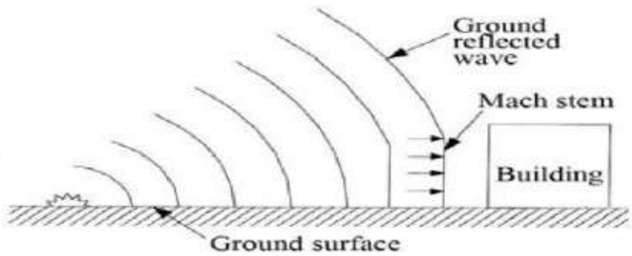

Figure.2. Surface burst

When an explosion occurs within a building, the pressures associated with the initial shock front will be high and therefore will be amplified by their reflections within the building. This type of explosion is called a confined explosion. In addition and depending on the degree of confinement, the effects of the high temperatures and accumulation of gaseous products produced by the chemical reaction involved in the explosion will cause additional pressures and increase the load duration within the structure. Depending on the extent of venting, various types of confined explosions are possible as shown in below fig 3.

Figure.3. Fully vented, partially vented and fully confined explosions

There are many forms of high explosive available and as each explosive has its own detonation characteristics, the properties of each blast wave will be different. TNT is being used as the standard benchmark, where all explosions can be expressed in terms of an equivalent charge mass of TNT. The most common method of equalization is based on the ratio of an explosive's specific energy to that of TNT.

ANALYSIS OF BLAST LOADS

Blast load is defined as triangular time history unction in the ETABS. Hinges are assigned to frame elements (beams and columns) at a relative distance of 0.1 and 0.9. Nonlinearity due to both material and geometry are considered. Hilbert-Hughes-Taylor (HHT) time integration method with default values for alpha, beta and gamma are used. Taking 100-time steps of each 0.01 seconds step size a non-linear time history direct integration analysis is carried out. Analysis of highway bridges under blast loads requires accurate generation and application of blast loads and good understanding of the behavior of components of bridge. The purpose of this paper is to introduce some ideas about blast load generation method like pressure wave method, detonation simulation method, hybrid blast load method and multi-Euler domain method. Also, verification of blast load results using hybrid blast load method and multi-Euler domain method included in this paper. With correct selection of the structural system, well designed beam-column connections, structural elements designed adequately, moment frames that transfer sufficient load and high-quality material; it's possible to build a blast resistant building. Every single member should be designed to bear the possible blast loading. For the existing structures, retrofitting of the structural elements might be essential. Although these precautions will increase the cost of construction, to protect special buildings with terrorist attack risk like embassies, federal buildings or trade centers is unquestionable.

Overhead Protection Structure

The design of several overhead protections (OHP) structures in terrorist affected areas for major oil operators and government agencies to protect their facilities housing their personnel such as office facilities and dining facilities. OHP structure usually consists of two layers: a pre-detonation layer and a shielding layer, as shown in below fig 4. The pre-detonation layer consists of plywood supported by steel beams, and this will cause the ordnance to explode upon impact. The shielding layer underneath consists of steel plates and sand bags supported by steel frames. The sand bags are intended to stop the fragmentation of the mortars or rockets while the steel plates and the supporting structural frames will resist the blast and impact loads. The lateral bracing shown in fig 4 are designed to resist seismic loads and wind loads.

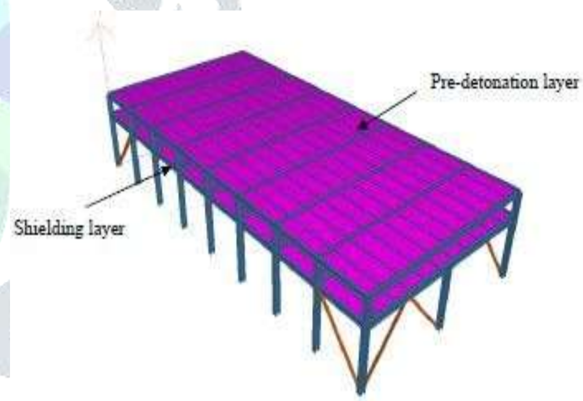

Figure.4. OHP Structure

The structural design of OHP structures to resist blast/fragment loads by 120 mm mortar and rockets is presented here. Blast/impact loads caused by 120 mm mortar and rockets were calculated and a structural design concept as described above was developed. The calculated peak blast load immediately below the ordnance on the shielding layer is as high as 11 MPa (1,600 psi). A finite element model using general-purpose finite element program ABAQUS/Standard was developed, and nonlinear finite element dynamic analysis of the structure was performed. The structure was designed and evaluated for blast/impact loads with "high damage" response criteria as defined in ASCE Guidelines (2010). The plywood thicknessused on the pre-detonation layer needs to be designed to cause the ordinance to explode upon impact, and the sand bag thickness on the Shielding layer needs to be sufficient to stop the fragmentation of the mortars or rockets. The distance between the pre-detonation layer and the shielding layer is about 1.5 m (5 ft). Other dimensions of the structure as well as detailed member sizes are not shown in this paper. The evaluation and justification procedure will be presented.

BLAST LOADING

Mortars and rockets of 120 mm produce both blast and fragmentation hazards. It is not necessarily the same item that produces the worst blast and fragmentation hazard. The severity of the blast hazard is directly correlated to the amount of explosive in the warhead. The fragmentation hazard is a function of both the explosive and casing details. To determine the blast loading on the structure, the configuration in below fig 4 was used. In the initial load calculations, h was assumed to be 1.5 m (5 ft). Using the resulting scaled distance (r /W1/3) and angle of incidence (a), the side-on and reflected pressures are determined as a function of x. The data comes from the imperial data of for spherical airburst scenarios (Kingery and Bulmash, 1984). No shield of the blast by the detonation layer is assumed. A certain charge weight and a commonly used explosive material were assumed. Table 1 shows blast load time history as a function of horizontal distance from the impact point, and reflected blast pressure, Pr, will be used in the structural evaluation.

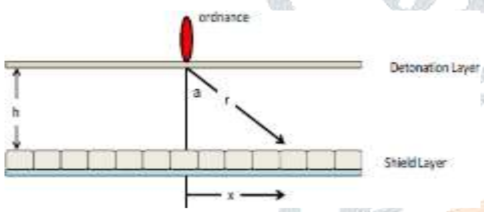

Figure.5. Configuration Assumed in the Blast Load Calculations

III. METHODOLOGY

The calculations are based on **IS: 4991-1968** which is the criteria for blast resistant design of structures for explosions above ground.

Models used:

Model 1: Shear wall of thickness 150mm

Case Study:

Case 1- Blast load of 150kg explosive at 25mstandoff distance
Case 2- Blast load of 150kg explosive at 50mstandoff distance
Case 3- Blast load of 250kg explosive at 25mstandoff distance
Case 4- Blast load of 250kg explosive at 50mstandoff distance

STRUCTURAL DETAILS

Description of Model:

Table 1: Description of Model	
No. of bays in x-direction	4
No. of bays in y-direction	4
Width of single bay in both directions	4m
No. of Storeys	20
Height of each storey	3m

Structural elements:

Table 2: Structural Elements		
Column	600mm x 600mm	M40
Beam	350mm x 550mm	M30
Slab	140mm thick	M30
Plinth	900mm thick	M30

General loading:

Table 3: Loadings	
Live load	3kN/m^2
Floor finish	1.5 kN/m^2
Imposed loads	2 kN/m^2

Model 1: shear walls of 150mm thickness is used

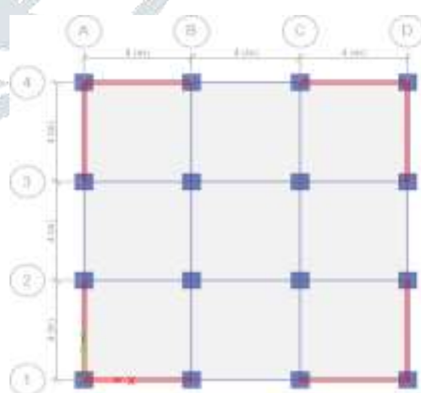

Figure 6. Plan view

Figure 7. Elevation

Table 4: Storey Displacement	Model 1
Storeys	mm
Base	0
PLINTH	21.4
Story1	49.7
story2	91.1
Story3	144.5
Story4	207.2
Story5	277.1
Story6	352.5
Story7	431.6
Story8	513.2
Story9	596.1
Story10	679.3
Story11	762.7
Story12	845.2
Story13	926.8
Story14	1006.9
Story15	1085.5
Story16	1162.3
Story17	1237.5
Story18	1311
Story19	1383
Story20	1453.9

IV. RESULT

Case 1: when 150kg of explosive is used at 25m standoff distance

Storey displacement

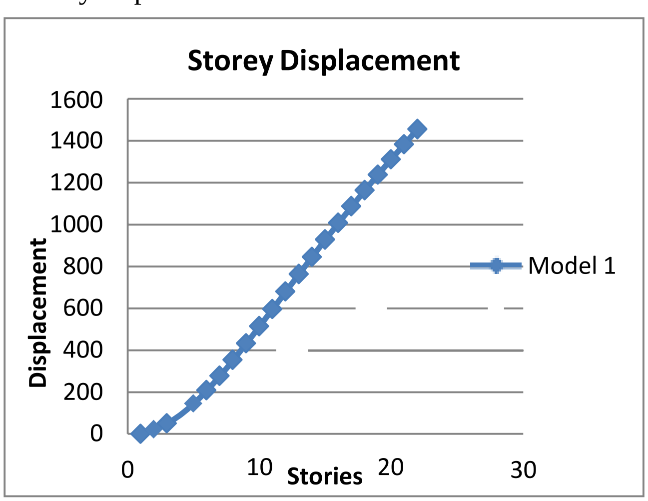

Figure 8. Analysis of Storey Displacement

Storey Drift

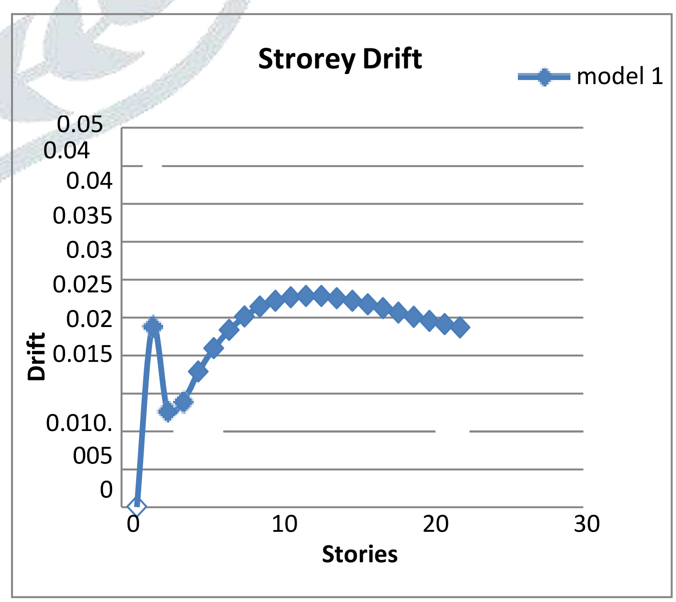

Figure 9. Analysis of Storey Drift

Table 5 : Storey Drift	Model 1
Storeys	
Base	0
Plinth	0.02382
1	0.012601
2	0.013856
3	0.01783
4	0.020938
5	0.023338
6	0.025124
7	0.026383
8	0.027196
9	0.027641
10	0.027791
11	0.02778
12	0.027532
13	0.027177
14	0.026718
15	0.026188
16	0.025621
17	0.025052
18	0.024511
19	0.024066
20	0.023682

Table 6: Storey Displacement	Model 1
Storeys	mm
Base	0
PLINTH	7.9
1	18.7
2	34.8
3	55.3
4	79.7
5	107
6	136.6
7	167.8
8	200.3
9	233.4
10	266.9
11	300.4
12	333.6
13	366.3
14	398.4
15	429.8
16	460.4
17	490.2
18	519.2
19	547.5
20	575.1

Case 2: when 150kg explosive used at 50mstandoff distance.

Storey Displacement

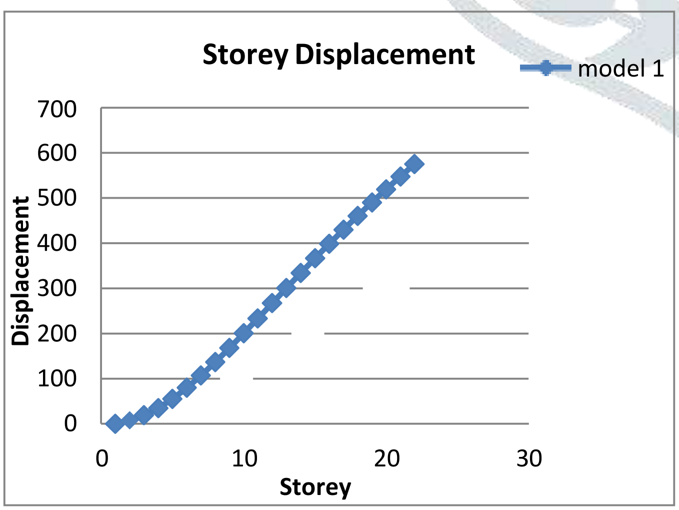

Figure 9: Analysis of lateral displacement

Storey Drift

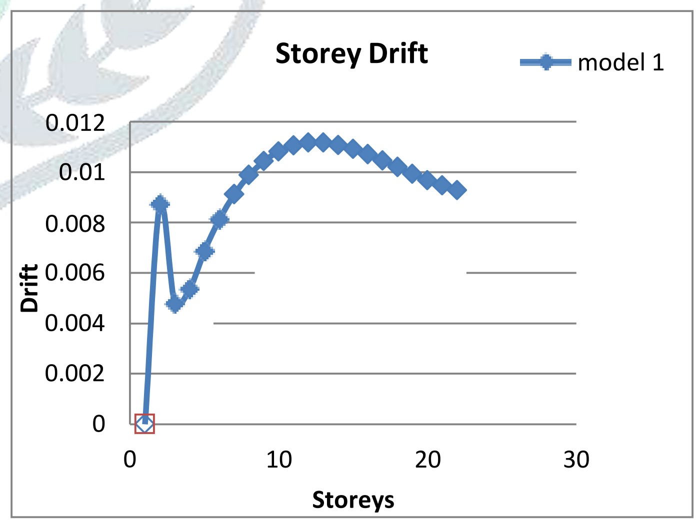

Figure 10: Analysis of Storey drift

Table 7: Storey Drift	Model 1
Storeys	
Base	0
PLINTH	0.008729
1	0.004794
2	0.005358
3	0.006873
4	0.008124
5	0.009114
6	0.009874
7	0.010434
8	0.010821
9	0.011057
10	0.011165
11	0.011165
12	0.011076
13	0.010916
14	0.010704
15	0.010458
16	0.010192
17	0.009925
18	0.009671
19	0.009466
20	0.009275

Table 8: Storey Displacement	Model 1
Storeys	mm
Base	0
PLINTH	11.1
1	46
2	99.9
3	166.8
4	244.7
5	331.1
6	423.5
7	520
8	619.1
9	719.4
10	819.6
11	918.7
12	1016.2
13	1111.3
14	1203.6
15	1293
16	1379.2
17	1462.5
18	1542.8
19	1620.8
20	1695.9

Case 3: when 250kg of explosive is used at 25mstandoff distance.

Storey Displacement

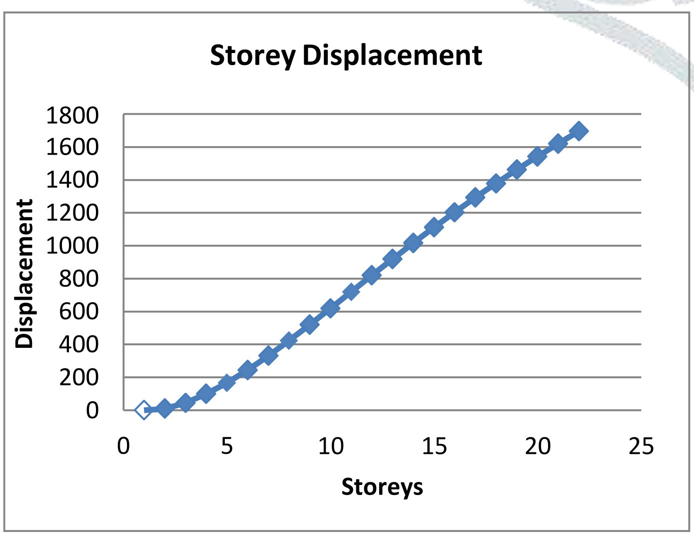

Figure 11: Analysis of lateral displacement

Storey Drift

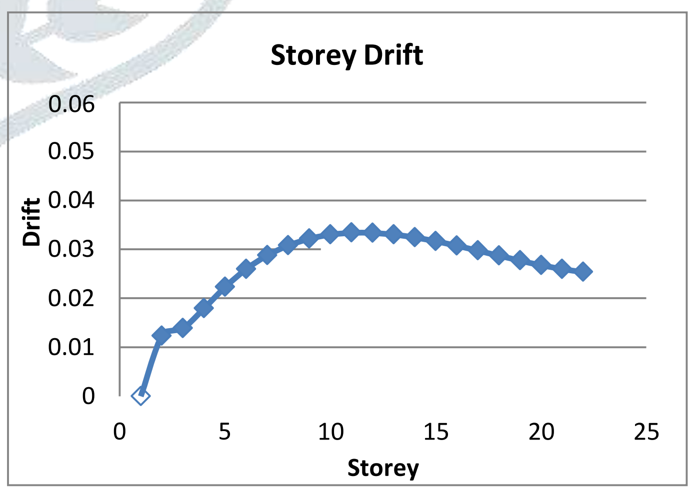

Figure 12: Analysis of Storey drift

Table 9: Storey Drift	Model 1
Storeys	
Base	0
PLINTH	0.012332
1	0.013897
2	0.017958
3	0.022339
4	0.02603
5	0.028824
6	0.030854
7	0.032237
8	0.033069
9	0.033437
10	0.033418
11	0.033081
12	0.032493
13	0.031711
14	0.030792
15	0.029789
16	0.028755
17	0.027744
18	0.0268
19	0.026029
20	0.025406

Table 10: Storey Displacements	Model 1
Storeys	mm
Base	0
PLINTH	3.3
1	12.8
2	27.4
3	45.8
4	67.3
5	91.3
6	117.1
7	144.1
8	172
9	200.3
10	228.6
11	256.8
12	284.5
13	311.7
14	338.2
15	363.8
16	388.7
17	412.8
18	436.1
19	458.9
20	480.8

Case 4: when 250kg explosive is used at 50mstandoff distance.

Storey Displacement

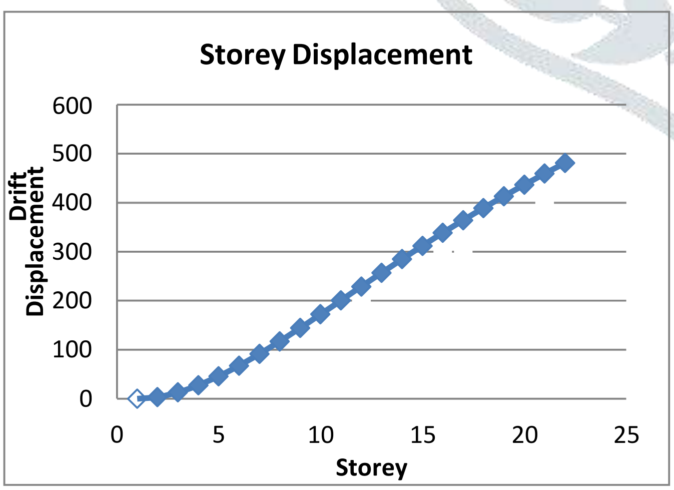

Figure 13: Analysis of lateral displacement

Storey Drift

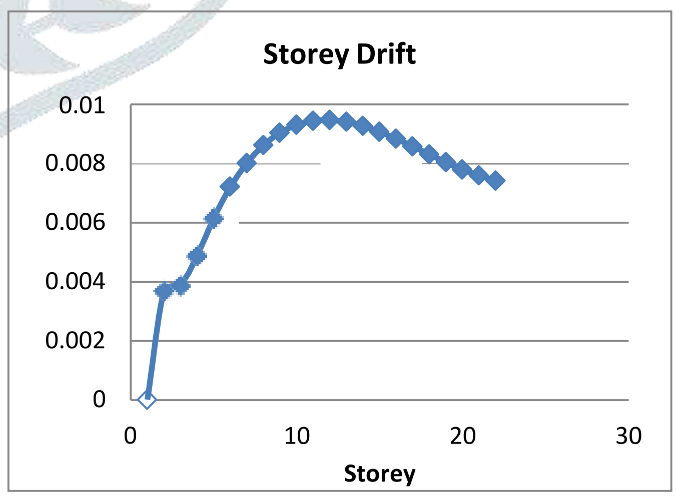

Figure 14: Analysis of Storey drift

Table 11 : Storey Drift	Model 1
Storeys	
Base	0
PLINTH	0.003681
1	0.00386
2	0.004874
3	0.006141
4	0.007196
5	0.008006
6	0.008607
7	0.009028
8	0.009295
9	0.009431
10	0.009457
11	0.009391
12	0.009253
13	0.009059
14	0.008824
15	0.008564
16	0.008294
17	0.008028
18	0.00778
19	0.00758
20	0.007407

V. CONCLUSION

Methodology for blast and impact resistant design of overhead protection (OHP) structures subjected to 120 mm mortars and rockets is described. OHP structure usually consists of two layers: a pre-detonation layer and a shielding layer. The pre-detonation layer consists of plywood supported by steel beams, and this layer will cause the ordnance to explode upon impact. The shielding layer underneath consists of steel plates and sand bags supported by steel frames. The sand bags are intended to stop the fragmentation of the mortars or rockets while the steel plates and the supporting structural frames will resist the blast and impact loads which can be computed.

Based on the studies so far carried out by several researchers following conclusions can be drawn.

1) With the increase in Blast load and decrease in the Standoff distance, the Displacement and Storey Drift increases rapidly. So the response of the structure completely depends on the standoff distance and blast load.
2) The maximum displacements are 1695.9mm and 1654.1mm for 250kg explosive from 25m standoff distance. And 1453.9mm & 714.2mm was the maximum displacement for 150kg explosive at 25m standoff distance.
3) Here, while using 250kg of explosive the thickness of shear wall was increased to 250mm but the grade of concrete used is M40 only.
4)

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