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A Review Paper on Blast Resistant Structure

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Abstract: **With advancement of technology, the increased numbers of terrorist attacks in last few decades necessitate dynamic effect of blast loading to take into account, like wind and earthquake load. The main object of this study is to access literature on blast load which the structure may subjected to, evaluation of vulnerability, and providing guidance to the designer to mitigate the effect of blast on building in economic way to provide protection to human and infrastructure against explosion. A case study is carried out on an RC column subjected to blast loading; effect of strength on deflection with time, strain rate on ductility is studied. Collapse mechanism is studied by following alternative path method for Minimum Design Loads for Buildings and other Structures. An analysis of a 2-storey building is carried out, and the effect of blast loading and standoff distance on the displacement and storey drift is studied, with addition of X-type bracings and shear wall to make the structure to be blast resistant. Structural, architectural and managerial aspects of design are also included in this report to make the structure to be blast resistant.**

Keywords - Blast Loading, Standoff Distance, Ductility, Collapse Mechanism, Aspects Of Design

INTRODUCTION

Blast loading was not so important in the earlier age. With the advancement of technology, the increasing numbers of terrorist activities in last few decades show the importance of taking the dynamic effect of blast loading in design of structure like wind and earthquake which are also unpredictable. Attacks are exceptional cases, man-made disaster and its probability of occurrence cannot be determined accurately. Also, terrorist activities can't be stopped. Extremist uses newer chemical and technology, which causes serious threats to life as well as property .Concerning safety of life property, the blast resistant design was brought into light. It is not economical and realistic too to design a completely blast proof structure. However; with the advancement of current engineering and architectural knowledge, various strategies can be followed right from the planning stage. The effect of blast can be mitigated to a large extent in new structure, and in existing structure too.

The main objective of the study is to access literature on blast load that the structure may subjected to, vulnerability evaluation, to provide guidance to the designer to mitigate the effect of blast on building in economic way to provide protection to human and infrastructure against multiple extreme events.

1.1. Explosive Type And Explosion

Some of chemical explosive are TNT, TATP, RDX, PETN and aziroazide azide etc. Among them TNT is the most commonly used explosive chemical as it is very easy and convenient to handle. Full form of TNT is tri-nitrate-toluene. Infect it is used as benchmark, where all other explosives are expressed in terms of equivalent mass of TNT and the most common method of equalization is ratio of specific energy of the explosive to specific energy of TNT.

There are mainly three type of explosion, namely unconfined explosion, confined explosion and explosion caused by explosive attached to the structure.

Unconfined explosion causes effect as an air burst or a surface burst. In case of air burst, detonation of explosive occurs above the ground level. An immediate amplification of shock wave is caused by ground reflection; prior to initial blast wave arrives the building. As the wave continues to propagate outward along the ground surface, a front is formed which is known as Mach stem; by interaction of initial waves and reflected wave.

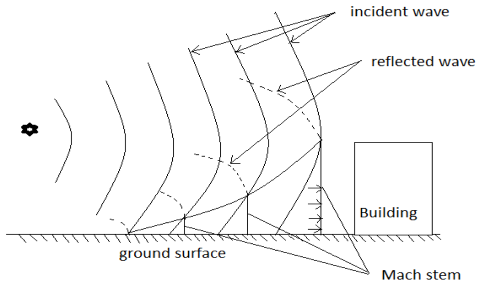

Fig 1: Air burst

Surface burst occurs when detonation is very close to or on ground surface. The initial shock waves get reflected and amplified by ground surface, which produces reflected waves. Unlike in case of air burst, reflected wave merges incident wave at the point of detonation; resulting in single wave. In most of cases of terrorist activities, in built-up areas, devices are placed on or very near to ground surface.

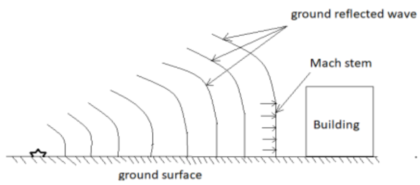

Fig 2: surface burst

When an explosion takes within the building, the pressure generated by initial shock front will be high, and as a result; reflections will be amplified within the building. Such type of explosion is commonly known as confined explosion. In addition to these depending upon degree of confinement, high temperature effect, accumulation of gaseous product resulting from chemical reaction during explosion will cause additional pressure, which will increase the duration of load within the structure. Based on extent of vent, various types of confined explosion may take place as shown in fig.1.7.

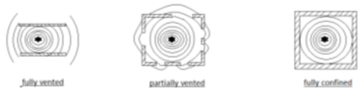

Fig 1.7: type of explosion

If explosive is attached with structural member like column, it will cause instantaneous stress, as the shock waves arrives the surface, resulting in crushing of material. Except this, an explosion within a structure will produce the same effect as those of confined and unconfined explosion.

1.2. *Shock Waves*

Explosion occurs when gas, liquid or solid material undergoes rapid chemical reaction and produces very high temperature and pressure near the source. As a result of explosion shock waves are generated; travels outward with very high speed in all direction from the point of detonation and forms blast waves; get reflected at any object. As the gas moves, they also cause air to move. Due to passage of compressed air of blast wave damage to the structure takes place. As the waves expand away from source, intensity of wave gets reduced and its effect on object gets reduced too. However; in case of enclosed passage, such as tunnel, the blast wave travels with very little diminution.

Due to the effect of blast the surroundings are subjected to different type of loading, which can be grouped under three heads; the effect in which surrounding air get compressed, known as air shock waves. Due to accumulation of gases due to chemical reaction of explosion, causes air pressure and air movement, which is known as dynamic pressure. The effects due to which the ground gets rapidly compressed, is known as ground shock waves.

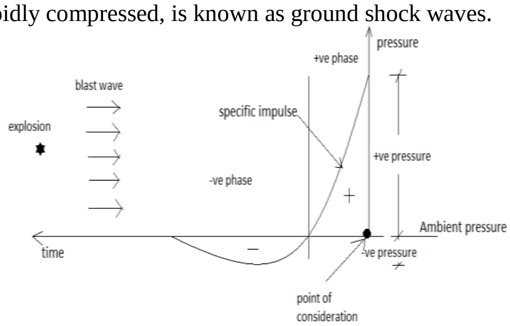

Fig 1.8: Shock waves created by blast

Air shock waves cause instantaneous increase in pressure above ambient atmospheric pressure at the point of consideration, some distance away from source; which is commonly known over pressure. As a result, differential pressure is generated between the atmosphere and gases; which is known as negative pressure. When air returns to its original state equilibrium state is reached.

1 kg of explosive produces about $1m^3$ of gases as per rough approximation and as gas expands outward, it displaced nearby air and objects and causes damage. The effects of dynamic pressure get diminished rapidly as it moves away from the source.

Ground shock wave consists of three principal components, wave travels radially from source known as compression waves; waves travel radially and particle moves in plane normal to the radial direction; where shock wave intersects with the surface, known as shear waves and a surface or Rayleigh waves; these waves propagates with different velocities and frequencies.

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.

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 building 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.

Zeynep Koccaz, et. al. (2008)includesresearch work of making a building blast resistant by putting various regulations into action, right from the stage of planning and layout to prevent loss of life as well as structural loss due to blast which has the greatest important to prevent the overall collapse of the structure. Here mainly architectural and structural designs are discussed. In architectural design, behaviour of structural elements such as walls, floors etc. and secondary structural elements like cladding, glazing etc. are considered. In structural design, elements are designed to resist structural load where all members should be considered and no member should fail under extreme loading condition. With accurately selected structural system, well designed beam-column joints, accurately designed structural element, it is possible to make blast resistant structure.

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 to show 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

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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 behaviour of three storey frame of Reinforced Cement Concrete and Slurry Infiltrated Fibre Reinforced Concrete (SIFCON) subjected to blast 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 totalling 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 on building, 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 the event 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.

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3. CASE STUDY

3.1. RC Column Subjected to Blast Loading: RC column of ground floor of height 6.4m of a multi-storied building is analysed in this case. Parameters considered for study are-

Strength- 40MPa for NSC (Normal Strength Concrete)

- 80MPa for HSC (High Strength Concrete)

Spacing of stirrups- 400mm for OMRF (Ordinary moment Resisting Frame)

-100mm for SMRF (Special Moment Resisting Frame)

It is found that by increasing compressive strength of concrete, size of column can be reduced effectively. Column of size (500×900) mm for NSC can be reduce to (350×750) mm for HSC, with the same axial load carrying capacity.

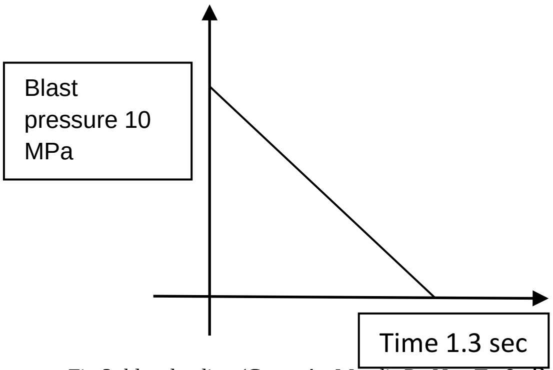

Fig 3: blast loading (Gupta A., Mendis P., Ngo T., & Ramsay J.;2007)

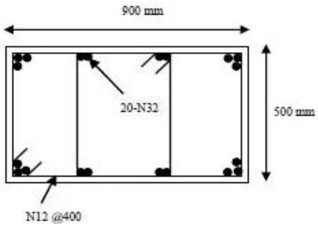

Fig 4: C/S of NSC column-ordinary detaling with 400 mm spacing (Gupta A., Mendis P., Ngo T., & Ramsay J.;2007)

Table 1: concrete grade, member size and spacing of stirrups

Column	Sizes (mm)	f_c (MPa)	Stirrup spacing
NSC	500×900	40	400mm and 100mm
HSC	350×750	80	400mm and 100mm

A 3-D column was analysed using nonlinear explicit code LS-Dyna3D (2002) taking into consideration of non-linearity of both material and geometry. Effect of blast loading are analysed dynamically to obtain the deflection time history of the column.

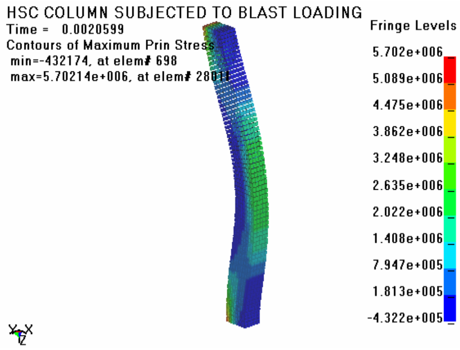

Fig 6: model of the column using explicit code LS-Dyna3D (Gupta A., Mendis P., Ngo T., & Ramsay J.;2007)

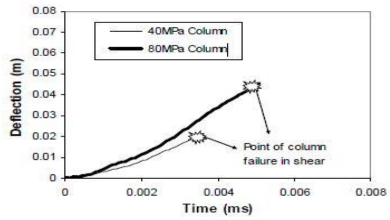

Fig 7: lateral deflection with time at mid-point of column with 400 mm spacing of stirrup (OMRF) (Gupta A., Mendis P., Ngo T., & Ramsay J.;2007)

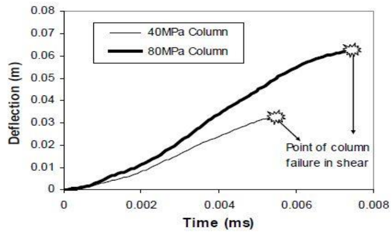

Fig 8: lateral deflection with time at mid-point of column with 100 mm spacing of stirrup (SMRF)(Gupta A., Mendis P., Ngo T., & Ramsay J.;2007)

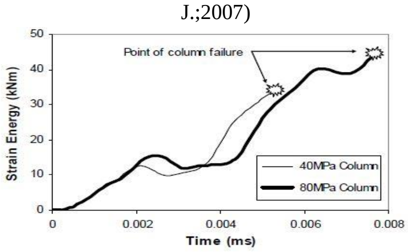

Fig 9 : comparison of energy absorption capacities with 100mm stirrup spacing (Gupta A., Mendis P., Ngo T., & Ramsay J.;2007)

Lateral deflection of column at mid height of column with time is shown in graphical form. (fig.8 and fig.9) for both NSC and HSC column which shows lateral resistance of column. It shows that at nearer standoff distance causes both NSC and HSC to fail by shear. However, HSC column of strength 80MPa with reduced cross section have higher lateral deflection, showing better energy absorption capacity, than NSC column of strength 40 MPa. From fig 8 and fig. 9, it is clear that, the effect of shear reinforcement is also significant. The ultimate lateral displacements at failure increase from 45 mm to 63 mm for stirrup spacing 400mm and 100mm respectively for the HSC column; which are 20mm and 32mm for the NSC with stirrup spacing 400mm and 100mm respectively.

Table 2: energy absorption at failure of HSC and NSC column

Column	400mm spacing	100mm spacing
NSC	12.0 kNm	33.9 kNm
HSC	27.6 kNm	43.5 kNm

3.2. Effect Of Strain-Rate On Ductility

It is evident that increase in the rate of loading will increase the strength and stiffness of concrete, yield strength of steel and also load carrying capacity of the flexural member. A parametric Study is carried out to investigate the effects of high strain-rate on the ductility of reinforced concrete members, and on their flexural capacities and shear capacities.

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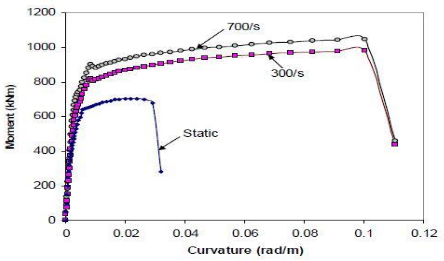

Fig 10: M-Ø curve of a cross-section of a column at different strain rates (Gupta A., Mendis P., Ngo T., & Ramsay J.;2007)

Fig 10 shows M-Ø relationship from which it is clear that, at high strain rate, as the yield strength and compressive strength of concrete increases flexural capacity and ductility of reinforced concrete beam also increases. The shear capacity of column is calculated using the Modified Compression Field Theory.

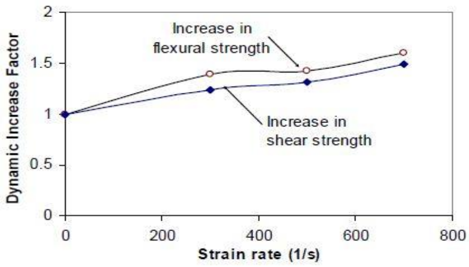

Fig 11: DIFs for flexural strength and shear strength of a column at different strain rates(Gupta A., Mendis P., Ngo T., & Ramsay J.;2007)

The above fig. 11 shows, at high strain rate, the increased ratio of flexural capacity (Mu.dyn/Mu.stat) and shear capacity (Vu.dyn/Vu.stat) is compared to those capacities under static loading. It is also observed that the increase in flexural strength is greater than the increase in shear strength; which shows increase in material strength under dynamic condition may cause brittle shear failure instead of ductile flexural failure.

3.3. Progressive Collapse Analysis

After the collapse of 22-storey Ronan Point apartment building, Design recommendations on progressive collapse analysis have been introduced in British Standards, since 1968. After that, a number of European countries, USA and Canada have included progressive collapse provisions in their building codes. The American National Standards Institute (ANSI) Standard A58.1-1982, “Minimum Design Loads for Buildings and other Structures” recommended the alternative path method, in which the local failure is allowed to occur but an alternative path must be provided around the failed structural members.

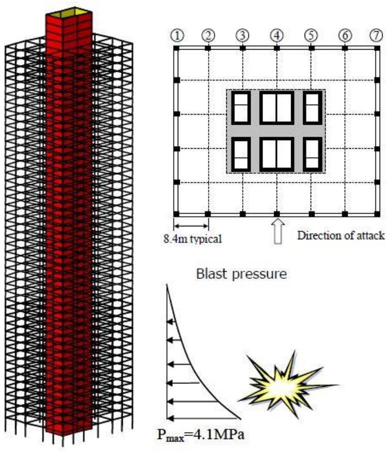

Fig12: structural configuration (Gupta A., Mendis P., Ngo T., & Ramsay J.;2007)

A 52 storey building of storey height 3.85m, a modified form of a typical building in Australia is analysed in this study. The plan and structural configuration of the building is shown in fig 12. The spacing of column is 8.4m C/C in the periphery, which are connected by spandrel beams to support the front face. The lateral loads are resisted by 6 core boxes located at the centre of the plan. The building is designed to resist lateral loads due to wind and seismic loading specified in Australian Loading Standards AS1170.2 and AS1170.4. The slab, columns and core walls are casted at site. The lateral load is resisted by Lateral Load Resistance System (LLRS) of the core walls, which is about 80% of the overall capacity.

Here, local damage of the example is studied due to bomb blast at ground level and progressive collapse of the building is analysed. By considering the effect of failure of column in the perimeter, spandrel beams, and floor slabs due to blast over-pressure, structural stability and integrity of the building is assessed. The main object of this analysis is to check if failure of any primary structural member will cause progressive collapse, which may propagate to a storey level, above or below the affected member vertically, or to the next vertical structural member.

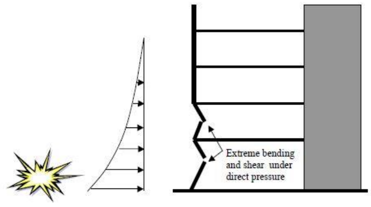

Fig 13: direct column loading (blast pressure)(Gupta A., Mendis P., Ngo T., & Ramsay J.;2007)

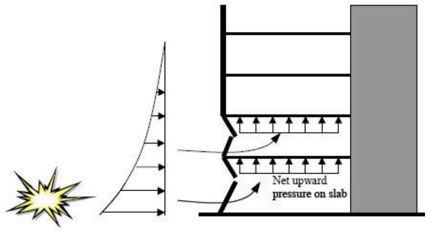

Fig 14: uplifting of floor slabs (blast pressure) (Gupta A., Mendis P., Ngo T., & Ramsay J.;2007)

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Fig 13 & 14 shows the effect of blast pressure on columns and beams on the perimeter of the building at perimeter and floor slabs. The thickness of slab of the building is 125mm, which is supported by pre-stressed wide band beams. The portion of slab nearer to blast, were hit by the blast over-pressure directly. The normal glazing in the facade of the building causes insignificant resistance to the blast wave. As a result, after failure of the glazing system, the blast fills the structural bay above and below of each floor slab. The pressure due to blast below the slab is greater than the pressure above it, and thus it causes net upward load on each slab.

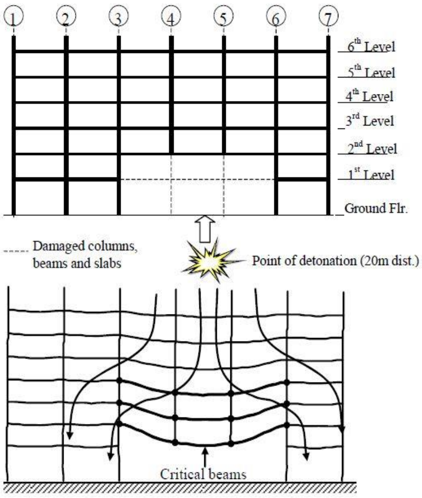


Fig15: progressive collapse analysis of the perimeter frame, caused by blast loading (Gupta A., Mendis P., Ngo T., & Ramsay J.;2007)

To detect local damage, the blast analysis is carried out on beams, and column on the perimeter of building and floor slabs, subjected to actual blast pressure on the each of element. In fig 15, results are plotted, which shows that column lines 4, 5 of the ground and 1st floor levels failed due to the direct impact of the blast wave. Also slabs and beams from column line 3 to 6 collapsed. Member assessments were carried out using program RESPONSE (2001) which is based on the Modified Compression Field theory and LSDYNA. It also shows that, if reinforcement detailing are as per the requirement of Special Moment Resisting Frame (SMRF), then shear capacity and ductility will be improve significantly, which will improve the blast and impact resistance of the member. In the damaged model of perimeter frame, failed elements were removed and again analysed to check whether progressive collapse would propagate beyond one story level above or below.

Fig 16 shows the alternative load path, which go through the columns surrounding the damaged area, from where the vertical loads are transferred. Due to the failure of the supporting columns, beams and floor slabs above that area become critical. The overall stability of the structure will depend on continuity and ductility of these elements which will redistribute forces within the structure. Falling debris, resulting from the collapsed members also imposes severe loading on the floors below, and thus it becomes essential to check whether that overload can be carried without causing further collapse or not.

Parametric studies are carried out to investigate the impact resistance of the floor slab, assuming a floor above had collapsed onto it, where collapsing floor was treated as falling debris. To obtain estimated impact load-bearing capacity of the floor slab, the structure was analysed using program LSDYNA. Along with non-linearity of material and geometry, membrane action, inertia effects, and other influencing factors are also considered in the analysis. Result shows, the ultimate capacity of the floor slab is approximately 16.5kPa which is 2.75 times of the total floor load (DL+0.4LL). Thus, in this case study if more than two floors collapsed, which will act as falling debris, will impose an additional load for the floor below, resulting in progressive collapse of the example building.

Design Methodology of Blast Resisting Structure

4.1. Methodology

A 2 storey structure with different weight of explosive (TNT) of 100Kg and 300kg at different standoff distance of 20m and 30m is considered for the study. Blast loading parameters are calculated as per IS4991-1968 (Reaffirmed 2003), and four different models are generated using ETAABS. Dimensional properties of frame chosen for study are:

The length and breadth of frame is 3 bays of 3.5m each and 3 bays of 3.5m each.

The 4 different models are:

- Model 1: structure with normal frame with column and beam size (400×400) mm and (300×400) mm respectively.
- Model 2: structure with normal frame with increased cross section column and beam size (600×600) mm and (400×600) mm respectively.
- Model 3: model 1 with addition of shear walls of thickness 150mm.
- Model 4: model 1 with addition of X shaped steel bracing.

The different load cases used for study are:

- Case 1: 100Kg of explosive at standoff distance of 30m.
- Case 2: 100Kg of explosive at standoff distance of 20m.
- Case 3: 300Kg of explosive at standoff distance of 30m.
- Case 4: 300Kg of explosive at standoff distance of 20m.

4.2. Load Calculations

Blast loadings are calculated as per IS4991-1968, and blast parameters are determined as follows:

For the 1st case:

As per clause 5.3, scaled distance, $\frac{actual\ distance}{W^{1/3}} = \frac{30}{0.1^{1/3}}$ =64.65

Where w=100Kg=0.1 tonne

From table-1, to determine blast parameter between distance 63m and 66m

Peak side-on over pressure, P_{so}=0.35 kg/cm²

Peak reflected over pressure, P_{ro}=0.81 kg/cm²

Dynamic pressure, q_o= 0.042 kg/cm²

Mach no. M= 1.14

The scaled time for the scaled distance 64.65m are obtained multiplied by to $0.1^{1/3}$ to the tabulated values of the respective quantities for the actual explosion of .1 ton charge.

Positive phase duration, t_o = $37.71 \times 0.1^{1/3}$= 17.5 milliseconds

Duration of equivalent triangular pulse, t_d= $28.32 \times 0.1^{1/3}$= 13.15 milliseconds

Shock front velocity, U= M.a = 1.14×344 = 392m/sec = 0.392 m/milliseconds

Where a= velocity of sound in air, 344m/sec at mean sea level at 20º C

4.3. Pressures On The Building

Here, H =6m, B=10.5m and L=10.5m and S=6m (either H or B/2)

Clearance time,$t_c = \frac{3S}{U} = \frac{3\times6}{0.392}$ = 45.91 milliseconds>t_d

Travel time of shock from front to rare face, $t_c = \frac{L}{U} = \frac{10.5}{0.392}$ = 26.7856 milliseconds>t_d

Pressure rise time on back face, $t_r = \frac{4S}{U} = \frac{4\times6}{0.392}$ = 61.22 milliseconds>t_d

As t_r>$t_d$no pressure on the back face, are considered.

From table 2, for roof and sides C_d = -0.4 (for $q_o = 0\ to\ 1.8\ kg/cm^2$)

As per cl.6.2.1.1. The net pressure acting on the front face at any time t is the lesser of i. and ii..

i. Reflected pressureP_{ro}= 0.81 kg/cm²

ii. $P_{so} + C_d \times q_o$= 0.35 – (0.4×0.042) = 0.33 kg/cm²

4.4. Load On Front Face Joints

Loads on centre joints = 81 kN/m²×3.5×3 = 850.5 KN

Loads on Side joints = 81 kN/m²×3.5×$\frac{3}{2}$ = 425.25 KN

Loads on Edge joints = 81 kN/m²×$\frac{3.5}{2}$×$\frac{3}{2}$ = 212.625 KN

4.5. Load On Roof And Side Walls

Loads on Centre joints = 33 KN/ m²×3.5×3 = 346.5KN

Loads on Side joints = 33 KN/ m²×3.5×$\frac{3}{2}$ = 173.25KN

Loads on Edge joints = 33 KN/ m²×$\frac{3.5}{2}$×$\frac{3}{2}$ = 86.625KN

Bracing used for the analysis of the system is ISLC 200Channel section.

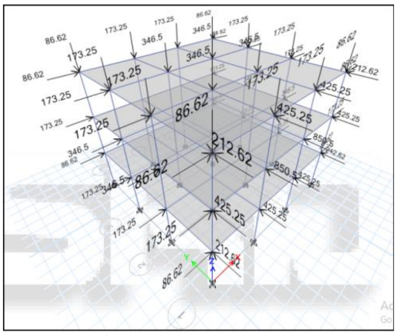


Fig 16: load application for case 1(Demin George, Varnitha M.S; 2016)

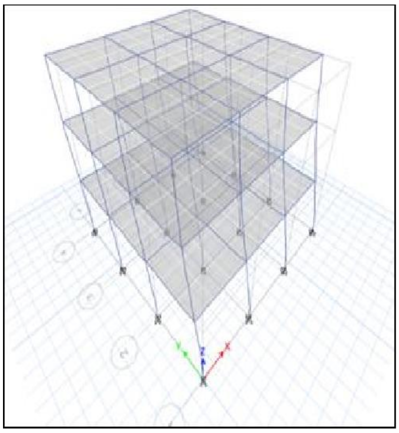
4.6. Results And Discussion

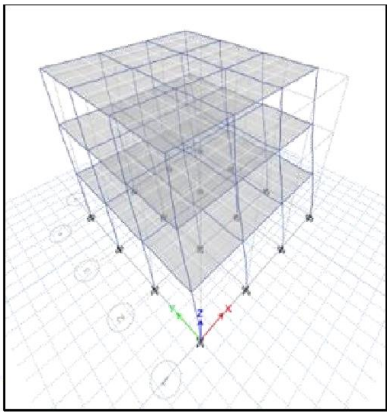
The models are generated and analysed by ETAB 2015, and loads are applied based on all the 4 load cases. Live load on floor is taken as 3 kN/mm² as per IS 875 part-2. The structure is analysed by non-linear static analysis as loads are converted to static joint loads.

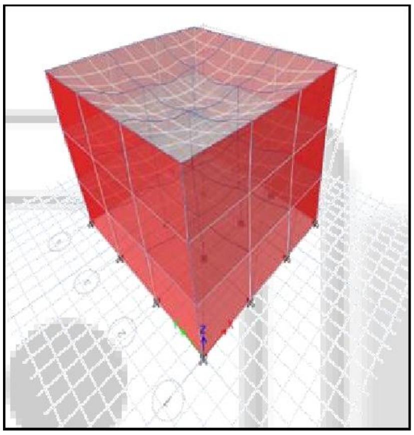
After analysis, result shows for the model 1; the maximum inter storey drifts are 54.3 mm, 21.4 mm for 300 Kg blast load from 30 m and 20 m standoff distance; and the max storey drifts are 10.5 mm,24 mm for 100kg blast load from 30 m and 20 m standoff distance. But as per IS 1893 maximum allowable storey drift is 12 mm (0.004×storey height). Thus, maximum storey drift are not satisfying IS code recommendation in model 1.

In model 2, for all the load cases, the cross-section of beams and columns are increased, compared to model 1, the maximum storey displacement and the maximum storey drift reduced by around 70%and 65% respectively.

The deformed shapes of the 4 models in case 1 is shown below.







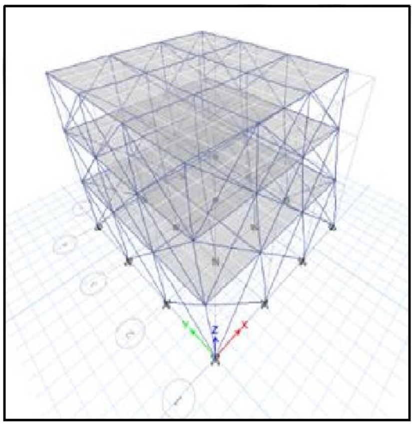


Fig 17: Deformed shape of mode 1, 2, 3 and 4 respectively
(Source: Demin George, Varnitha M.S; 2016)

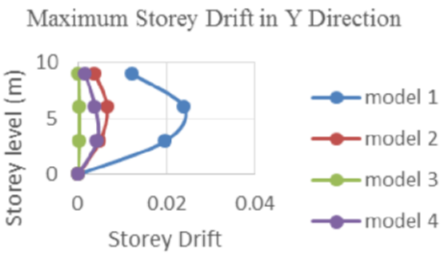


Fig 17: maximum storey drift in case 1

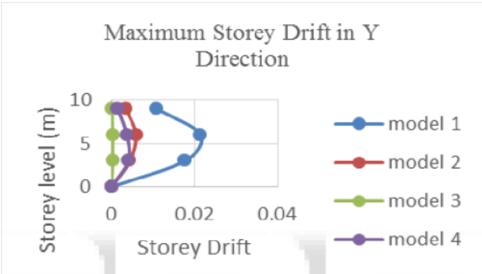


Fig 18: maximum storey drift in case 2

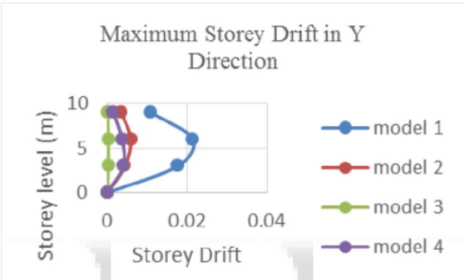


Fig 19: maximum storey drift in case 3

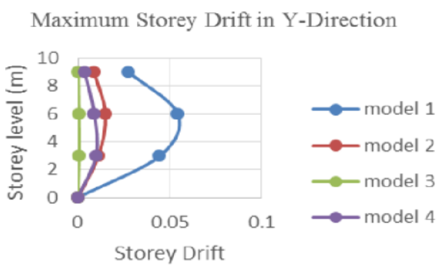


Fig 20: maximum storey drift in case 4
(Source: Demin George, Varnitha M.S; 2016)

Storey displacements and storey drifts are shown in figure in X direction, as storey displacements and storey drifts in Y direction are too low and within permissible limit.

In model 3, addition of shear walls all around the structure in model1 reduces maximum storey displacement and max storey drift by around 95%, as compared to model 1. In this model shear wall is found is found to be effective to reduce storey displacement; by maximum displacement and maximum story drift within the permissible limit as per IS 1893.

In model 4, addition of steel bracing around the structure helps to reduce the maximum storey displacement and maximum storey shear by almost 80% as compared to maximum storey displacement and storey shear of model 1.

4.7. Conclusion And Recommendation: As per the results obtained from analysis, following points can be concluded:

A. As the blast loading increases and standoff distance decreases the maximum displacement and story drifts increases. Blast parameters are dependent on blast load and standoff distance. Thus the structure response depends on blast load and standoff distance.
B. By increasing the size of beams and columns, the resistance of the structure can be improved, but it is practicable from view point of serviceability of the structure; as the limit of serviceability may not be fulfilled by huge cross section of beams and column.
C. Addition of shear wall and X type steel bracing resist blast loading effectively. Use of steel bracing around the structure gives good result; but the shear wall gives more desirable results than steel bracing and it is economical too.

5. STRUCTURAL, ARCHITECTURAL AND MANAGERIAL ASPECTS OF BLAST RESISTING DESIGN OF STRUCTURE

5.1. Structural Aspects

Front face of a building experiences the peak overpressure created by blast waves and it decays to zero as the initial blast waves passes the reflected surface of the building. The front face experiences a relieving effect of blast; as the sides and the top faces of the building are exposed to overpressures. The rear of the structure experiences no pressure until the blast wave travels the length of the structure and a compression wave begins to move towards the centre of the rear face. There will be a time lag in the development of pressures and loads on the front and back faces, which is caused by translational forces to act on the building in the direction of the blast wave. Therefore, the pressure built up is not instantaneous.

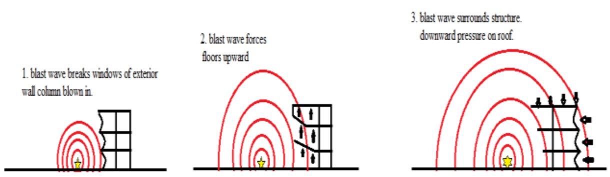


Fig 21: sequence of air-blast effects (Fatih Sutcu, Necdet Torunbalci, Zeynep Koccaz; October,2008)

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Though the blast loadings are extra ordinary load cases, their effect should be take into account in adequate ratio, during structural design. As the static design the dynamic design of blast resistant structural design also uses the collapse limit design and serviceability limit design. The target of the design is to provide enough ductility, to prevent overall collapse of building. In case of an explosion, significant translational movement and moment will occur and the loads should be transferred from the beams to columns. The structure doesn't collapse after the explosion however it cannot function anymore.

However, as per serviceability limit design the building should function properly after an explosion. Only non-structural members like windows or cladding may need maintenance after an explosion, so that they should be designed ductile enough.

The kind of blast loading, in which positive phase of the shock wave is shorter than the natural vibration period of the structure, is defined as "impulsive loading". Here, before the structure responds, explosion effect vanishes. When the positive phase is longer than the natural vibration period of the structure, this kind of blast loading is defined as "quasi-static loading. In this case, the load can be assumed constant when the structure has maximum deformation. This maximum deformation is a function of the blast loading and the structural rigidity. In case the positive phase duration is similar to the natural vibration period of the structure, the behaviour of the structure becomes quite complicated which can be defined as "dynamic loading".

Normal building frames designed to resist gravity, wind loads and earthquake loads have been found to be deficient in two respects. Beam-to-column connections can be subjected to very high forces during an explosion. These forces will have a horizontal component arising from the walls of the building and a vertical component from the differential loading on the upper and lower surfaces of floors. Providing additional robustness to these connections can be a significant enhancement.

In connections, the normal details for static loading have been found to be inadequate for blast loading. Especially for the steelwork beam-to-column connections, it is essential for the connection to bear inelastic deformations so that the moment frames could still operate after an instantaneous explosion. Figure 31 shows the side-plate connection. The main feature is, extra links are used in the reinforced concrete connection, which are used to reduce the risk of collapse or the connection be damaged, possibly as a result of a load reversal on the beam.

In critical areas, full moment-resisting connections are made in order to ensure the load carrying capacity of structural members after an explosion. Beams acts primarily in bending may also have to carry significant axial load during blast.

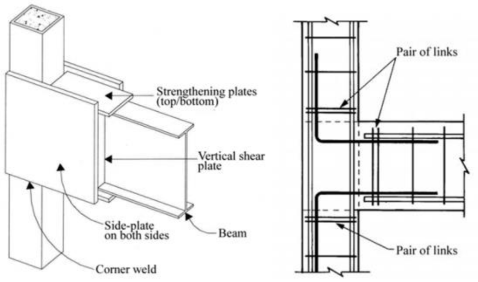

Fig 22: beam-to-column connection details (Fatih Sutcu, Necdet Torunbalci, Zeynep Koccaz; October,2008)

Normally columns are designed for axial loads which may be subjected to bending during the event of blasting; this can be lead to loss of load-carrying capacity of a section. Columns of a reinforced concrete structure are the most important members that should be protected, in case of an explosion. Two types of wrapping can be used in this case; wrapping with steel belts or wrapping with carbon fibre-reinforced polymers (CFRP).

Cast-in-situ reinforced concrete floor slabs are the preferred for blast resistant buildings, but precast floors may also be used in some circumstances. Use precast floor units are not recommended for at first floor as the risk from an internal explosion is the greatest. Lightweight roofs specially, glass roofs should be avoided and a reinforced concrete or precast concrete slab is to be preferred.

5.2. Architectural Aspects

The target of blast resistant design is to minimize damage to the structure in the event of an explosion. A primary requirement is to prevent catastrophic failure of the entire structure or large portions of it. It is also necessary to minimize the effects of blast waves transmitted into the building through openings and to minimize the effect.

5.2.1. Planning and Layout

From planning stage of a new building; potential threats and the associated risks of injury and damage can be reduced. The instant terrorist attacks show the necessity of blast protection for structural and non-structural members, adequate placing of shelter areas within a building. To reduce an external threat, stand-off distance between an external bomb and the building should be increased as possible. In location like city areas this can be achieved by providing obstructions such as bollards, trees and street furniture. Figure 23shows a possible external layout for blast safe planning.

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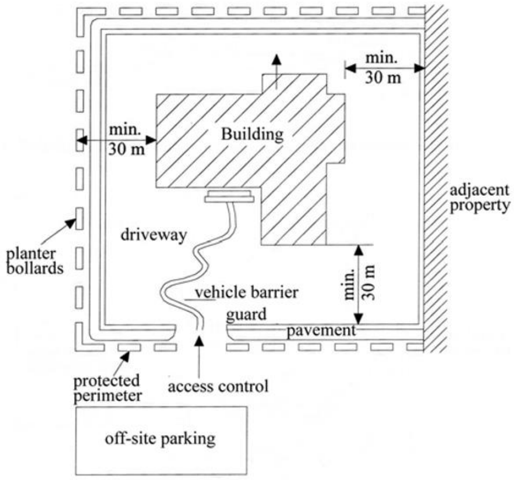

Fig 23: layout of site for protection against bombs (Fatih Sutcu, Necdet Torunbalci, Zeynep Koccaz; October,2008)

5.2.2. Structural Form And Internal Layout

Structural form is greatly affected by the blast loads. Structural forms like arches and domes reduce the blast effects better than a cubicle form. The plan-shape of a building also has a significant influence on the magnitude of the blast load, to which the building is subjected to. Complex shapes cause multiple reflections of the blast wave, and thus should be avoided. Projecting roofs or floors, and U-shaped building in plan are undesirable for this reason. It should be noted that single story buildings are more blast resistant compared to multi-storey buildings. Partially or fully embed buildings are quite blast resistant, as such structures take the advantage of the shock absorbing property of the surrounding soil. The soil provides protection in case of a nuclear explosion too.

The internal layout of the building should be so arranged that the highest exterior threat is separated by the greatest distance from the asset. Foyer areas should be protected with reinforced concrete walls; double-dooring should be used and the doors should be arranged eccentrically within a corridor to prevent the blast pressure entering inside of the building. The building entrance should be controlled and separated from other parts of the building by robust construction for greater physical protection. An underpass or car parking below or within the building should be avoided unless the access is effectively controlled. The internal members should be designed to resist fire, as a fire may occur after an explosion, which will increase damage catastrophically

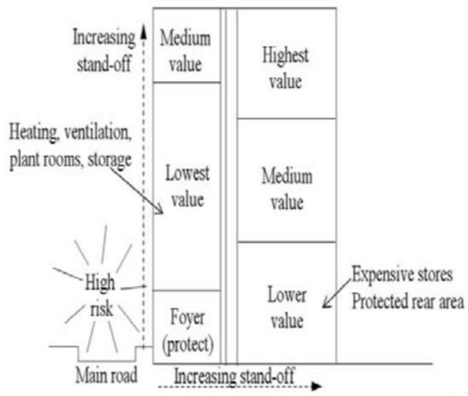

Fig 24: internal planning of a building (Fatih Sutcu, Necdet Torunbalci, Zeynep Koccaz; October,2008)

5.2.3. Bomb Shelter Areas:

The bomb shelter areas are specially designated areas within the building where vulnerability from the effects of the explosion is minimal and which personnel can retreat in the event of a bomb. These areas must afford reasonable protection against explosions; should be large enough to accommodate the personnel, and be so located to facilitate continual access. In case of modern-framed buildings, shelter areas should be located away from windows, external doors, external walls and the top floors. Areas should be surrounded by fullheight concrete walls and underground car parks, gas storage tanks, light weight partition walls like internal corridors, toilet areas, or conference should be avoided while locating the shelter areas. Basements can sometimes be useful shelter areas, after ensuring that building does not collapse on top of them.

The functional aspect of a bomb shelter area is to accommodate all the occupants of the building; providing adequate communication with outside; sufficient ventilation and sanitation.

5.2.4. Installations:

Gas, water and electrical connections, steam installations, elevators and water storage systems should be planned to resist any effect of explosion. Installation connections are critical points that should be considered and should be avoided to use in high-risk deformation areas. Areas like external walls, ceilings, roof slabs, car parking spaces and lobbies, which are considered to be high risk area should be avoided to locate the electrical and other installations. The main control units and installation feeding points should be protected from direct attacks, and as far as possible a reserve installation system should be provided for a potential explosion and should be located remote from mail installation system.

5.2.5. Glazing And Cladding:

Broken glasses of windows may be responsible for a large number of injuries caused during an explosion in a city centre. Choosing a safer glazing material is critical and it has been found out that laminated glass is the most effective in this aspect. On the other hand, application of transparent polyester anti-shatter film to the inner surface of the glazing is also an effective method. For cladding, several design

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aspects should be considered to minimize the vulnerability of people within the building and damage to the building. The amount of glazing in the facade of the building should be minimized, which will limit the amount of internal damage from the glazing and the amount of blast that can enter. The cladding should be fixed to the structure securely with easily accessible fixings and this will allow rapid inspection of any failure or movement.

5.3. Managerial Aspects

Risk and risk reduction process:

Risk is the net negative fallout of a hazard on the asset. The value of the assets, and the vulnerability of the asset can be represented as

RISK= P {Hazard × Value × Vulnerability}

The risk management concept is related to aspect commonly used to characterize the likelihood of the occurrence of an unwanted event and is commonly associated with terrorist threats.

Whether the building is new or an existing one, risk reduction process involves the following steps as shown in fig.25

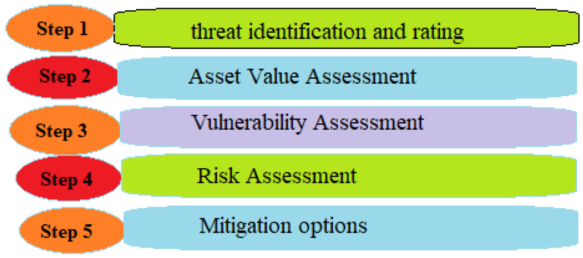

Fig 25: steps involved in risk reduction process (Bhor Amol.S, Prof. Salunkhe H.H; March 2016)

Step1: threat identification and rating involves identifying threats; collecting information; determining design basis threat and determine threat rating.

Step 2: Asset Value Assessment involves identifying possible layers of defence; identify critical assets; identify building core functions and infrastructure; and determine asset value rating.

Step 3: Vulnerability Assessment involves organizing resources to prepare the assessment; evaluate the site and building; preparing a vulnerability portfolio; and determining vulnerability rating.

Step 4: in Risk Assessment process; risk assessment charts are prepared, risk ratings are determined and building components prioritised.

Step 5: Mitigation options are Identify preliminary mitigation options; review mitigation options based on cost estimates; reviewing mitigation, cost, and layers of defence. Clearly, the process of risk reduction is comprehensive and requires a holistic approach. Each of the steps and tasks listed are helpful in designing of terrorist resistant.

CONCLUSION:

Blast effect causes ‘air burst’ when detonation is above and ‘surface burst’ when detonation takes place near ground. A large amount of research works was carried by many investigators, as the number of terrorist attack has been increased day by day with advancement of technology; in which effect of blast waves, modelling and analysis of RCC structure is done and design considerations are discussed.

A case study is carried out in this report in an RC column subjected to blast loading, NSC and HSC are considered for study, in which deflection and energy absorption of the both concrete is observed; which shows that at nearer standoff distance causes both NSC and HSC to fail by shear. However, HSC column of strength with reduced cross section have higher lateral deflection, showing better energy absorption capacity, than NSC column of strength, effect of shear reinforcement is studied.

A Study to investigate the effects of high strain-rate on the ductility of reinforced concrete members, and on their flexural capacities and shear capacities is studied. From M-Ø relationship it is clear that, at high strain rate, as the yield strength and compressive strength of concrete increases, flexural capacity and ductility of reinforced concrete beam increases; and also it shows if the increase in flexural strength is greater than the increase in shear strength; which results in increase in material strength under dynamic condition may cause brittle shear strength instead of ductile flexural failure.

A 52 storey building is considered to study the progressive collapse mechanism. The local damage of the example is studied due to bomb blast at ground level and progressive collapse of the building is analysed, by considering the effect of failure of column in the perimeter, spandrel beams, and floor slabs due to blast over-pressure, structural stability and integrity of the building is assessed, to check if failure of any primary structural member will cause progressive collapse, which may propagate to a storey level, above or below the affected member vertically, or to the next vertical structural member. If reinforcement detailing is as per the requirement of Special Moment Resisting Frame
(SMRF), then shear capacity and ductility will improve significantly, which will improve the blast and impact resistance of the member.“Minimum Design Loads for Buildings and other Structures” which recommends the alternative path method to study collapse mechanism, where the local failure is allowed to occur, but an alternative path must be provided around the failed structural members, and failed structure is considered as surcharge debris load for design.

A 2 storey building is analysed with different weight TNT of 100Kg and 300kg with stand-off distance of 20m and 30m is considered for the study. Blast loading parameters are calculated, and four different models are generated using ETAABS with normal frame, normal frame with increased cross section of beam and column, and addition of X bracing and shear wall. The effect of blast loading and standoff distance on drift and displacement is studied. Results shows as the blast loading increases and standoff distance decreases the maximum displacement and story drifts increases. By increasing the size of beams and columns, the resistance of the structure can be improved, but it is practicable from view point of serviceability of the structure. Addition of shear wall and X type steel bracing

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will resist blast loading effectively. Use of steel bracing around the structure gives good result; but the shear wall gives more desirable results and it is economical too.

Structural, architectural and managerial aspects of blast resistant design in also included in this report. As per structural requirement, to be blast resistant, all the structural members should be ductile, so that there may be local failure, but the overall failure of the structure should not take place. For which special attention should be paid to beam column joints. In critical areas, full moment-resisting connections are made in order to ensure the load carrying capacity of structural members after an explosion. Beams acts primarily in bending may also have to carry significant axial load during blast. Columns of a reinforced concrete structure are the most important members that should be protected, in case of an explosion. Similarly, in case of slab, cast-in-situ reinforced concrete floor slabs are the preferred for blast resistant buildings, but precast floors may also be used in some circumstances. Similarly building planning and lay-out of building should be made and structural form and internal layout be designed in such a way that it reduces the effect of blast. To reduce the effect of blast, stand-off distance should be increased by providing bollards, trees and street furniture. Uniform shaped single storey buildings are more blast proof than complex shaped and multi-storied buildings. Bomb shelter area should be provided with sufficient capacity should be provided to accommodate the occupants during the event of blast. Gas, water and electrical connections, steam installations, elevators and water storage systems should be properly planned and installed; laminated or transparent polyester anti-shatter film applied to the inner surface of the glazing should be used and cladding should be fixed to the structure securely with easily accessible fixings and this will allow rapid inspection of any failure or movement. Threats should be identified and rated, value of assets, vulnerability and risk assessment should be done and mitigation options should be reviewed properly.

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