Response of Reinforced Concrete Structural Components Subjected to the Blast Loading

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Abstract— **A explosion within or nearby a structure causes disastrous damage to internal and external structural system. These explosions cause masonry walls to collapse, blowing out large stretches of windows and closing all critical life-safety systems. Casualty occur due to direct contact with blast, structure failure, buried under debris, fire or smoke. Major catastrophes from gas-chemical explosions are cause for rise in large dynamic loads greater than the actual design loads. Efforts have been made to develop design and analysis methods to reduce the threats from extreme loading conditions. Study carried out on response of concrete under impact loads, enhance the understanding the role of structural design play in affecting the behaviour. Analysis and design of buildings under blast loads requires detailed study of dynamic response of structure. In this paper, the response of RC frame subjected to internal blast loads is studied. The RC frame was modelled in a finite element software (Abaqus). For the response evaluation, an internal explosion was first created inside a room and the equilibrium state was determined.**

Index Terms— **explosion, impact, Abaqus, impact, structural response, air blast, simulation.**

I. Introduction

Due to terrorist events in the past, design of structures against blast loading got importance. The conventional structures are not analysed for blast load. When blast loads are considered in design, the cost of design and execution becomes uneconomical. Recent incidents in the country forced the designers finding answers for protecting the occupants and building from blast loading [11]. Special courtesy is given for blast loads on ground breaking structures, such as sky scrapers in urban cities. The explosions inside and around the structure can affect the structural integrity of the building. Such damage to internal and external building frames can collapse entire system. The performance of high-rise buildings under influence of blast is of great importance to provide buildings which reduce damage to structure and property in the event of explosion. The analysis and design of blast resistant structures involves detail study on blast phenomenon, blast effects and the nature of explosives.

Objective

To accurately model flexural steel reinforcement as well as vertical shear reinforcement, study of interaction between flexural and shear reinforcement is a significant task. Broad assessment of the reliability of non-linear analysis for understanding reinforced building components subjected to impact loading react has been addressed.

Significant objectives addressed by this thesis are as to examine the effect of different non-linear material models which are accessible in the ABAQUS/Explicit material archive on the dynamic response of reinforced structural components, evaluate the effect of modelling different types of reinforcement in reinforced structural components subjected to impact loading and to simulate the distribution of crack and determine critical regions of elements.

Scope

To achieve the above objectives, tasks involving computations were carried. RC frame with openings has been subjected to dynamic loadings and the effect of blast pressure on structural components is evaluated.

II. Background

A. Explosion and Blast Phenomena

A Blast or explosion is outcome of an instant discharge of enormous energy confined to a limited space. Explosions are divided based on their nature as chemical, physical and nuclear events [12].

i) In Chemical Explosion: In chemical explosion, quick oxidation of fuel components (carbon and hydrogen atoms) is the prime source of energy.
ii) In Physical Explosion: In physical explosion, energy is unconstrained from the disastrous failure of cylinder containing compressed gas, volcanic eruption or mixing liquids at different temperature.
iii) In Nuclear Explosion: In nuclear explosion, energy is released from the construction of different atomic nuclei. It is caused by redistribution of the protons and neutrons within the inner acting nuclei.

The catastrophic action of a nuclear weapon due to blast or shock is much more severe than that of a conventional weapon. In a typical air burst at an altitude below 1,00,000 ft., an approximate distribution of energy would consist of 50% blast or shock, 35% thermal radiation, 10% residual nuclear radiation and 5% initial nuclear radiation [12].

A shock wave is a rapid release of energy which triggers a pressure wave in the surrounding atmosphere. As the wave travels far away from the point of explosion, the interior part that was previously compressed travels through the region

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and gets heated by the foremost part of the wave. As the pressure waves travels with the velocity of sound, the temperature reaches 3000°C-4000°C [12] and the pressure is around 300 kb of the air cause this velocity to surge. The inner part of the wave starts to move faster and overtakes the leading part of the wave. After a short duration, the pressure wave front becomes rapid thus forming a shock. The maximum pressure forms at the shock front and is known as the peak overpressure. Behind the shock front, the overpressure falls very rapidly to about one-half the peak overpressure and remains constant in the core part of the explosion.

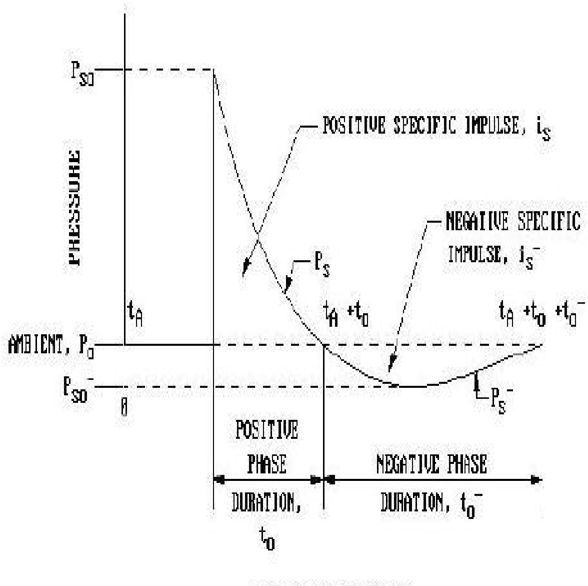

Figure1. variation of overpressure with distance at a given time from centre of explosion [8].

The pressure behind the front falls off in a standard manner without being constant. After the session, at a certain distance from the centre of explosion, the pressure behind the shock front decreases than that of the surrounding atmosphere and is called Negative Phase.

B. Difference between Blast Loads and Seismic Loads

Blast loadings are applied over a considerably short duration of time than seismic loads. Thus, the material strain rate effects become dangerous and are included to evaluate performance of short period loadings such as blast loads. Blast loads usually are applied non-uniformly onto a structure. There is difference in load amplitude across the surface of the building and radically reduces on the sides and end of the structure. The effects of blast loads are largely local, leading to severe damage or failure. Seismic loads are ground motions applied unvaryingly across the base of the building. All building components are subjected to “shaking” in association with this motion [11].

The difference between seismic excitations and blast-resistant design is the need for distribution of ductility over the entire building. Strong ground motions disturb entire lateral resisting system. The resistance to blast loading is more concentrated near the point where explosion occurred. The plastic hinges in the beams spread throughout the structure, as the Moment resisting frames provide high ductility and energy absorption.

The beam-column connections will develop flexural hinge in the beam. The distribution of deformation is inelastic throughout the structure. The elements are proportioned to prevent plastic story mechanisms which limit the inelastic energy absorbed in the isolated regions of the frame. This is achieved by “strong-column, weak-beam” (SCWB) methodology for blast and seismic resistant design. Since blast loading is more localized than seismic excitations, the resulting plastic hinge is more limited to a small area, with more severe rotations than those from strong ground movements. Structural systems such as concentrically and eccentrically braced frames can efficiently resist the lateral forces due to seismic activities. Such kind of systems can be considered on a case by case basis for use in blast-resistant design.

C. Influence of Blast Loads on Structures

The reflection of shock front influences the stress and duration of impulse. The ground under the explosion reflects the waves on to the surface of building. The pressures are magnified as a function of proximity, material characteristics of impacted object post reflection. Stronger the object, greater is the reflected energy because a lesser amount of energy is dissipated by the response of the surface. These variations are often neglected in conservative design [11].

Facades are designed to reflect the shock waves perfectly. Designers assume that the facade components remain static for duration of the impact shock front, causing peak pressures and impulses sufficient to reverse their direction. There is displacement of the facade during the blast loading. The displacement of façade reduces the efficiency of the reflector. Designing the facade to resist the blast load makes the structure become a support for blast loads. Depending on performance conditions, designers validate resistance of the framing system against applied loads. The building shall remain standing with an acceptable level of damage.

III. Finite Element Modelling

Due to restrictions in computing technology in the past, many structural analyses were led based on the basic SDOF model. Although the SDOF method can provide engineers with a sensible estimation of structural response, it cannot provide detailed analysis on the localized structural failure under extreme blast loading. The finite element method is more commonly used for structural analysis and in specific it has become an essential tool to model and simulate reinforced concrete system.

Analysis in Abaqus is done in three discrete steps: pre-processing, simulation, and post-processing. In pre-processing stage, geometry of building is defined and an Abaqus input file is created. The simulation generally runs in background is the step in which Abaqus solves the numerical problem defined in the step one. In post-processing,

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after simulation, the evaluation of the results is done and the stresses, displacements and other required variables are calculated.

The following steps are performed and graphs for stresses and displacements are plotted.

1. Defining and creating parts
2. Generating material properties and assigning section properties
3. Model Assembly
4. Creating steps for analysis
5. Assigning boundary conditions and loads on the model
6. Meshing the Domain
7. Submitting the job
8. Results Review

Fig.2 to Fig.8 represents the modeling of the structure in order as mentioned above.

Simulation of a G+1 RC Building Subjected to Blast Loading:

The span, length and width of the building are 5.0m c/c, 10.0 and 10.0m respectively. The height of storey is 4.5m. The building height is 9m. Width of Wall has been taken as 0.15m with floor thickness as 0.125m. The building is standing free and is only fixed at the bottom. The density, Young's Modulus and Poisson's Ratio of the concrete are 2.5E-005 N/mm^3, 2.5e4 N/mm^2 and 0.2 respectively. The density, Young's Modulus and Poisson's Ratio of the steel has been taken as 7.335E-005 N/mm^3, 2e5N/mm^2 and 0.3 respectively. The density, Young's Modulus and Poisson's Ratio of the wall has been assumed as 1.9E-005 N/mm^3, 4.22e3 N/mm^2 and 0.3 respectively. A Blast caused in a room on the 1st floor for period of 0.01 seconds. A uniform distributed blast pressure loading was applied. Amplitude at time zero seconds is 167550 which are forced onto the structure for period of 0.01 seconds.

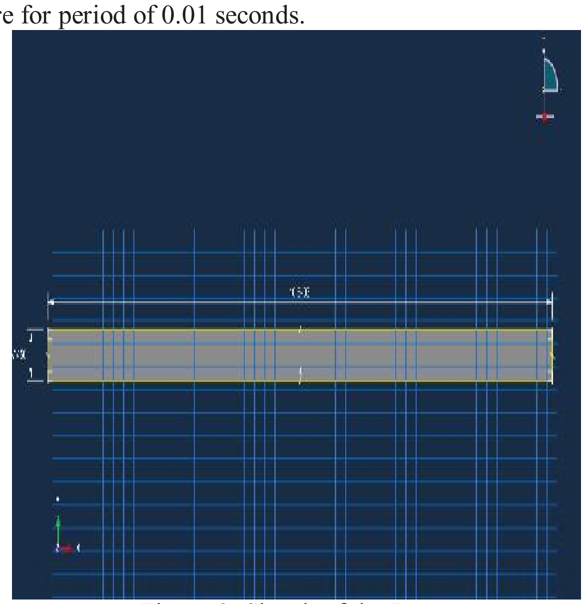

Figure 2. Sketch of the Beam

Figure 3. Isometric View of the Beam after Extrusion

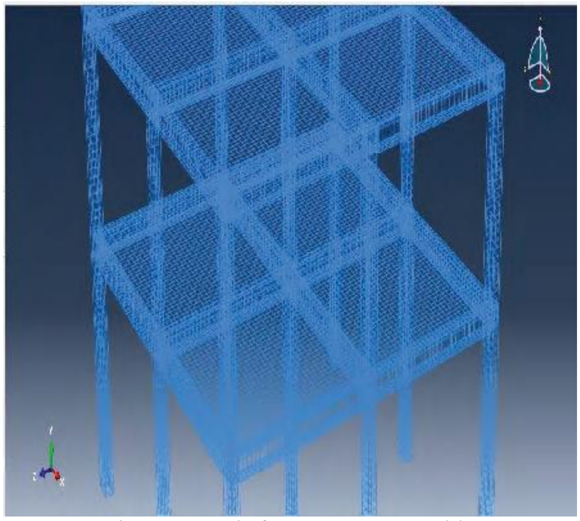

Figure 4. Reinforcement Assembly

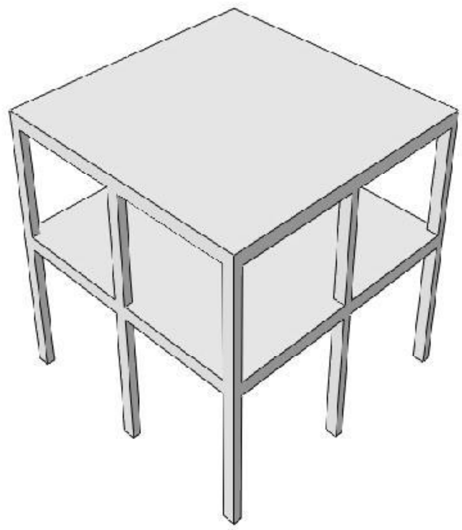

Figure 5. Frame Assembly

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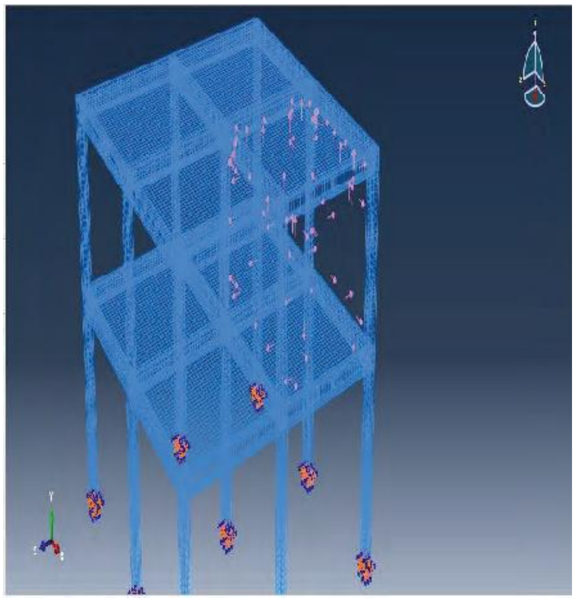

Figure 6. Blast loading in the room and Boundary Conditions (Fixed)

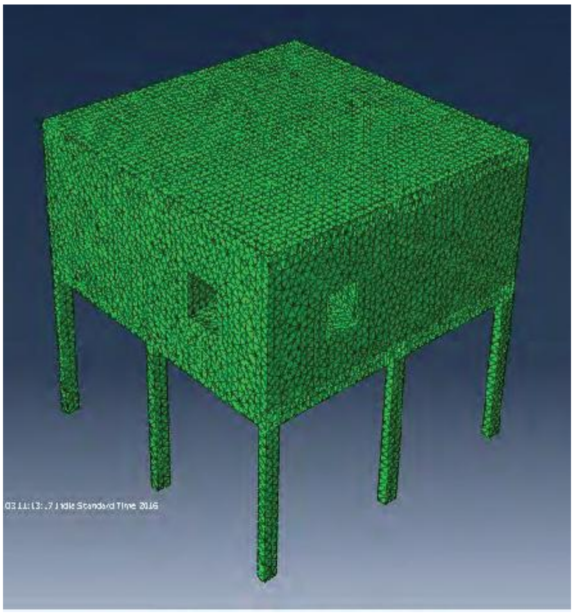

Figure 8. Second Order Tetrahedral Element having 10 Nodes for each Element

The meshing is done in two stages. In the first stage, the part instances are seeded. In the second stage, meshing the part instance is done. The number of seeds is based on the element size or the number of elements along an edge. Abaqus arranges the nodes of mesh at the seeds wherever possible. This process of seeding will generate tetrahedral elements. The type of tetrahedral element is C3D10M, Second Order Tetrahedral Element having 10 Nodes.

After meshing, the last step is to create a Job step which is submitted for analysis. After completion of Job submitted, results for blast loading analysis can be observed from visualization tab. Node wise displacements and stresses can be obtained using monitor option in the job tab.

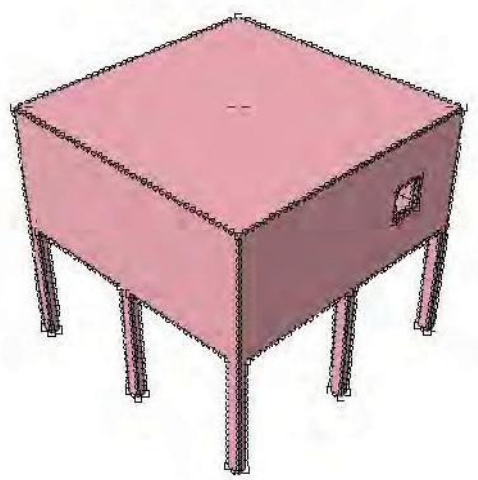

Figure 7. Seeding of Instance before Meshing

IV. Results

This chapter provides results and discussion on determining the variation of stresses and displacements under the blast impact caused by the explosion. In this case the entire room section on the first floor of the building, up to 4.5 m above ground level, failed under blast loading.

Sudden pressure is applied to the inner walls, ceiling and on floor of the room. All elastic models were constructed using Abaqus/CAE. Isometric views along with different sectional elevation and plans are illustrated below to examine the variation of stresses in the structure.

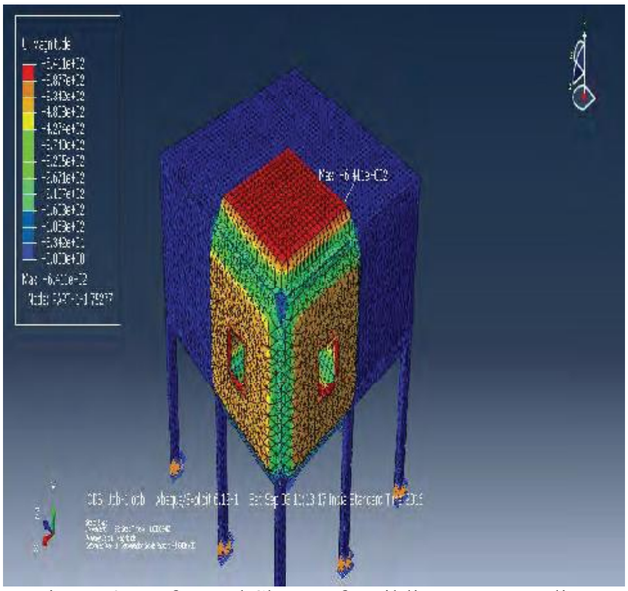

Figure 9: Deformed Shape of Building Post Loading

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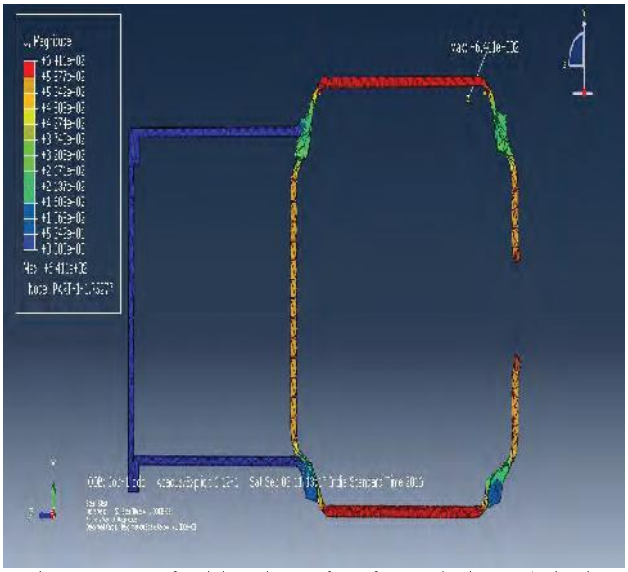

Figure 10: Left Side View of Deformed Shape (Displacement)

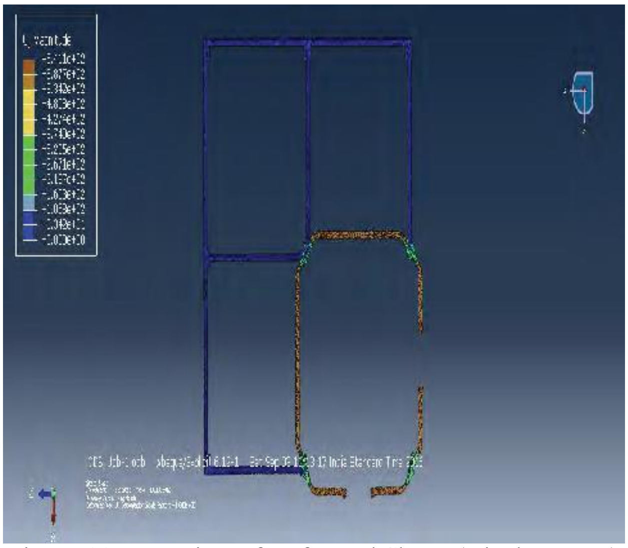

Figure 11: Top View of Deformed Shape (Displacement)

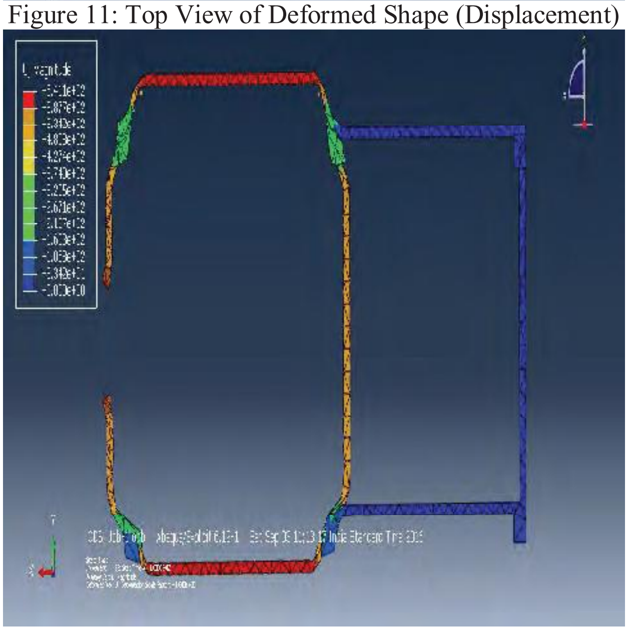

Figure 12: Right Side View of Deformed Shape (Displacement)

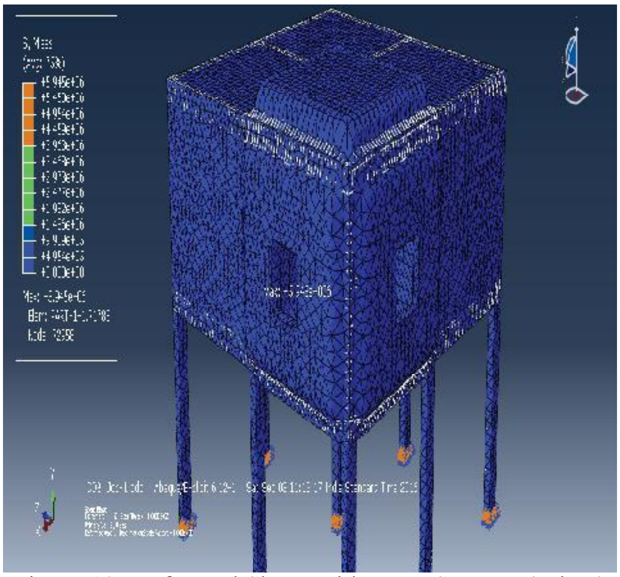

Figure 13: Deformed Shape with Max. Stresses (Mises)

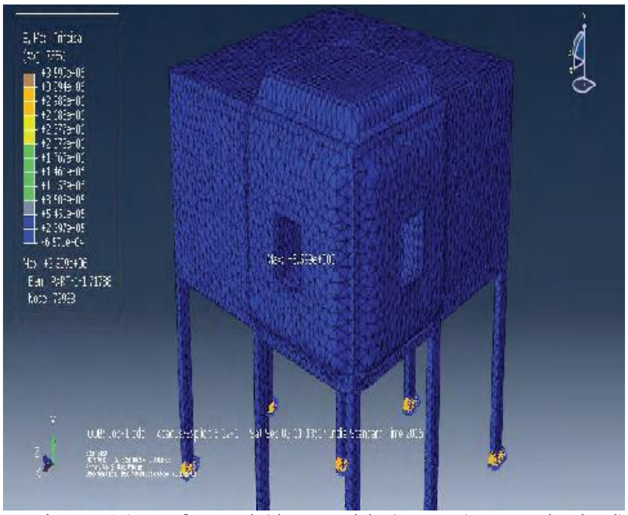

Figure 14: Deformed Shape with Stress (Max Principal)

Key Points of Analysis for the Maximum Principle Stress from the Blast Load were the explosion of the room encompassed around the openings. Stress inside the room propagate in a circular fashion making their way to the corners as shown in fig. 14. The walls of the building give a bouncing back or 'recoil' effect leading to high concentration of stress. The Maximum Principal stress value has been simulated to be 3.599E+06 N/mm^2 as in fig. 17. Rebounding of the building occur causing high localised displacement.
Key Points of Analysis for the Maximum Displacement from the blast load were explosion in the room caused maximum displacements at the openings, centre of slab and at joins as in fig. 9 and fig. 15. The largest displacement value has been simulated to be 6.411E+02 mm. Further increase in load caused distortion of structure. From the graph (fig. 16) the displacements were maximum at the centre and gradually reduce towards the joints. The deformed shapes at various sections have been shown in fig. 10 to fig. 12.

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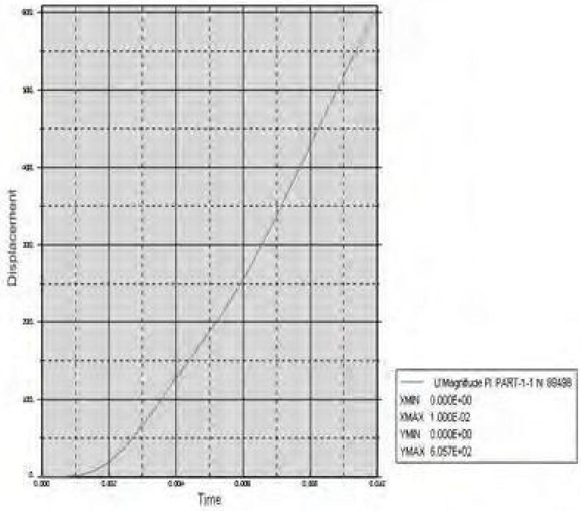

Figure 15: Time vs Displacement at Node Located at Max Deformation

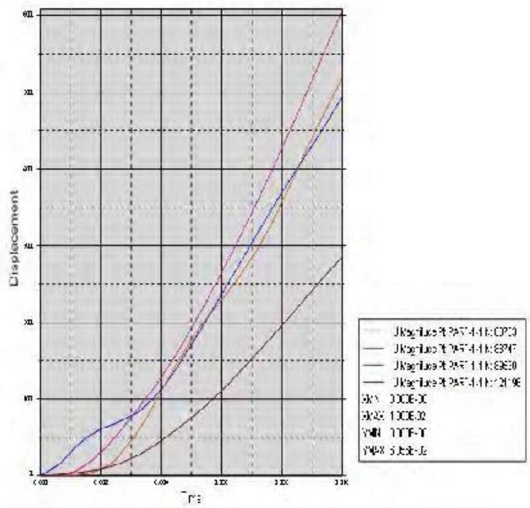

Figure 16: Time vs Displacement at Node Located at various Deformations

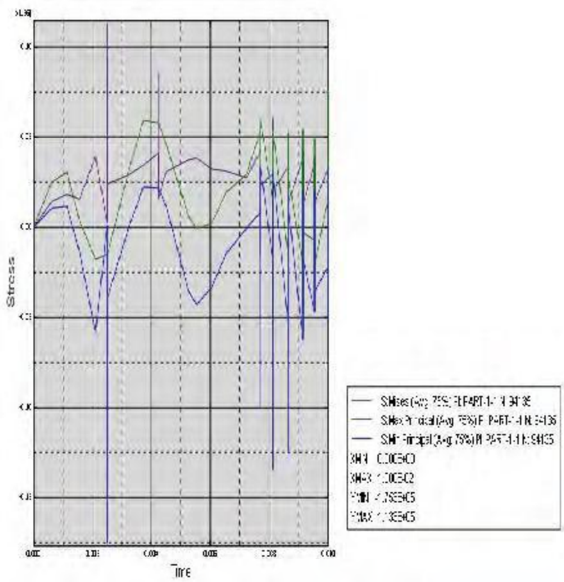

Figure 17: Time vs Stress (Mises), Max. & min. Principal Stresses

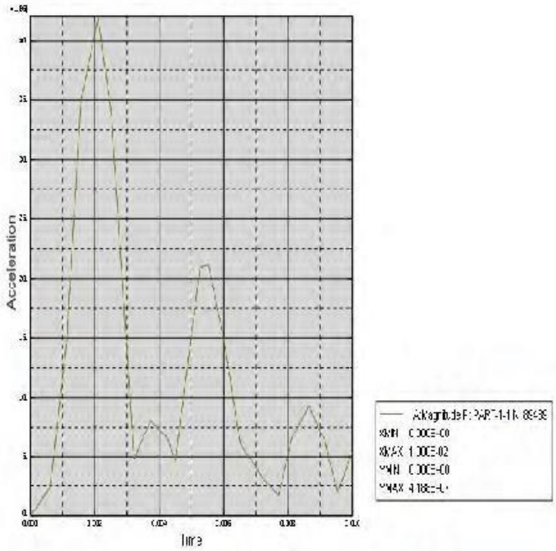

Figure 18: Time vs Acceleration

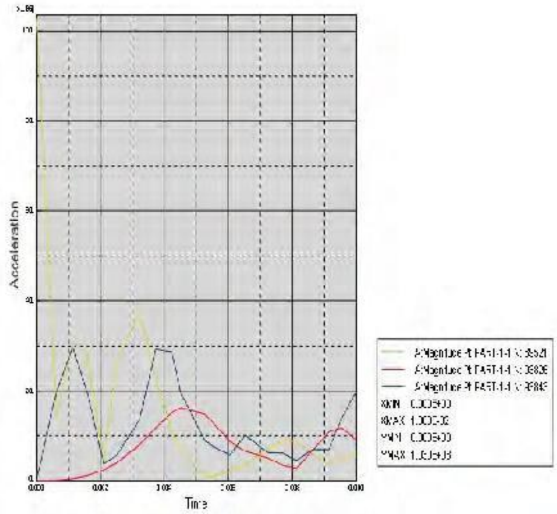

Figure 19: Time vs Acceleration at three nodes located at various deformations

Fig. 18 shows the variation of acceleration of elements with respect to time at node having maximum deformation or displacement. The difference in acceleration is shown with respect to time in fig. 19 at three different nodes in decreasing order of their displacements.

From research paper [13], it is seen that maximum stress from an 8-storey masonry building was 90,000N/mm^2. For 2-storey reinforced building with same dimensions, the maximum stress was 1, 67,550 N/mm^2. This shows that the reinforced structure offers more resistance to such blast loadings. Further, the resistance can be improved by additionally providing bracings or shear walls at surfaces fully exposed to blast loads.

V. CONCLUSIONS

A simple overview of the different types of loads is discussed here. When the blast load hits the structure, the blast pressure leads to an increase in the kinetic energy of the structural system. The increase in velocity results in a large displacement of the elements.

A two-bay two floors reinforced concrete structures have been modelled in Abaqus. The blast loading [13] is applied on the structure. The entire domain is discretized using ten node tetrahedron elements. The finite element analysis has been performed for different conditions of blast load. The maximum stress for an RC building is found to be 1.86 times the maximum stress for an 8-storey masonry building [13].

The finite element analysis revealed that, there exists a critical blast impulse for reinforced buildings. Blast impulse applied above the critical value will result in the collapse of building before the allowable deflection criterion is reached. The column and beam response to blast loads has shown to be significantly influenced by higher deformations.

The surfaces of the structure exposed to direct blast pressures cannot be protected. They are designed to resist the blast pressures by increasing the stand-off distance or designing the component against blast loading. High risk facilities such as public and commercial tall buildings the design considerations against extreme events (bomb explosion, high velocity impact) are very important.

The guidelines on abnormal load cases and provisions for progressive collapse prevention should be included in the current Building Regulations and Design Standards. Study on ductility requirement helps in improving the building performance under extreme load conditions.

Based on the results, some recommendations are made for future work concerning structures exposed to blast loads. All components constructed in this research are not pre-stressed. Therefore, it is necessary to develop a user defined material so that the pre-stressed concrete material model can be incorporated into the finite element model.
Multiple blast explosions are very likely to take place in terrorist attacks, especially for important structures. Hence, it is necessary to examine the structural response when subjected to such attacks. Based on the presented results, it appears that the employment of hollow section components in a structure can give a better blast resistance than filled section components under the blast load. Further investigation on this issue is necessary so that it can be incorporated into future blast resistant design. This research was only performed on a specific reinforced concrete building. As mentioned early in the study, different concrete structures exhibit disparities in structural integrity. Therefore, further research on various building types such as RC frame with stiffeners, bracings, shear walls, etc., are essential to determine their performance against blast load.

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