RESEARCH REVIEW JOURNALS
Volume-04
Issue-07
July-2019

ISSN: 2455-3085 (Online)
RESEARCH REVIEW International Journal of Multidisciplinary
www.rrjournals.com[Peer Reviewed Journal]

Nonlinear explicit analyses of RC columns under blast loading using Finite Element Method

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ARTICLE DETAILS

Article History
Published Online: 15July 2019

Keywords
Nonlinear explicit analysis, TNT, Blast loading, column, concrete damage plasticity, CONWAP.

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ABSTRACT

The columns are utmost important and most vulnerable part of the structures, the ideology of strong column and week beam is to prevent total collapse of the building while resisting the lateral loads and therefore columns should be built with high safety parameters. Thus column with greater stiffness than beam is provided. The present work deals with three dimensional nonlinear finite element (FE) analyses of a reinforced concrete column subjected to blast loading. The finite element package ABAQUS/Explicit was used to model a reinforced concrete column and the concrete damage plasticity approach was used to define the non-linearity of concrete. The stress-strain response of concrete and reinforcement has been simulated using concrete damaged plasticity model and elastic-perfectly plastic model, respectively. TNT explosive has been simulated using Air blast interaction under CONWEP definition. Parametric sensitivity studies have been performed by varying the spacing between stirrups as 125, 175, 225 and 275 mm and also diameter of main reinforcement bars are varied as 16, a20, 25, 28 and 32 mm to determine the displacement and stress variations. Efforts are also made to determine the effects of incident blast wave falling on the different face of the column. It is observed from the results that modeled column structure undergo significant deformation with variations. It is also observed that blast resistance increases as the spacing between stirrups decreases. Also, deformation of the column decreases as the diameter of the reinforcement bars increases.

1. Introduction

The threat of terrorism rising all over the world has increased the awareness among people. There have been many structural failures in the past incidents like Oklahoma City bombings, Scud missile attacks and Khobar towers bombing in Saudi Arabia. Efforts have been made to design structures which offers better resistance against blast explosion. Studies are being conducted on the behaviour of structural members subjected to blast loads. Designing buildings to resist failure due to blast loads is an extremely complex procedure. But, with the recent increase in public awareness of possible terrorist attacks worldwide, many organizations and agencies are currently trying to secure methods of constructing facilities that will survive blast loads due to explosions. During the 1960s, an extensive research program was funded by the governments to develop criteria for the analysis anddesign of blast-resistant structures. A majority of the early academic research in the field of blast design was done at the University of Illinois at Urbana-Champaign and at the Massachusetts Institute of Technology. This resulted in the Tri-Services Manual designed by the Army as “TM 5-1300: Structures to Resist the Effects of Accidental Explosions,” which was subsequently revised in 1990. This revision incorporates the research conducted over the intervening period.

The need and requirements for blast resistance in buildings have evolved over recent years. Buildings have become more complex and have increased in size thus increasing the risk of accidental explosions. Such explosions have demolished the buildings, in some cases resulting in substantial personnel causalities and business losses. 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.

2. Explosion process for high explosives

Explosion occurs when a gas, liquid or solid material goes through a rapid chemical reaction. When the explosion occurs, gas products of the reaction are formed at a very high temperature and pressure at the source point. These high pressure gasses expand rapidly into the surrounding area and a blast wave is formed. Because the gases are moving, they cause the surrounding air to move. The damage caused by explosions is produced by the passage of compressed air in the blast wave. Blast waves propagate at supersonic speeds and reflected as they meet objects. As the blast wave continues to expand away from the source of the explosion its intensity diminishes and its effect on the objects is also reduced. Close to the source of explosion, the blast wave formed is violently hot and expanding gases will exert intense loads which are difficult to quantify precisely. Once the blast wave has formed and propagating away from the source, it is convenient to separate out the different types of loading experienced by the surrounding objects. Three effects have been identified in three categories are,(a)Air Shock Wave-the effect rapidly compressing the surrounding air. (b)Dynamic Pressure- The air pressure and air movement effect due to the accumulation of gases from the explosion chemical reactions

(c) Ground Shock Wave - the effect rapidly compressing the ground.

The air shock wave produces an instantaneous increase in pressure above the ambient atmospheric pressure at a point some distance from the source.

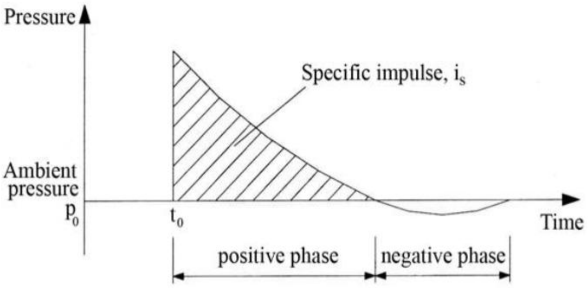


Fig.1 Blast wave pressures plotted against time. (01).

As a consequence, a pressure differential is generated between the combustion gases and the atmosphere, causing a reversal in the direction of flow, back towards the center of the explosion, known as a negative pressure phase. This is a negative pressure relative to atmospheric, rather than absolute negative pressure as shown in fig-1. Equilibrium is reached when the air is returned to its original state. [01]

The basic methodology that we have adopted in our study is non-linear dynamic analysis. Since in the case of heavy loading that acts for very short time (dynamic loading), the geometry of the structure changes and the stress induced due to the loading does not makes linear relation with the strain and big displacement occurs in the structure.

3. Literature Review

In the literature study, analyses on effects of blast loading on various structures have been carried out. ZeynepKoccazet,al [1] shed light on blast resistant building design theories the enhancement of building architectural and structural design process to provide security against the effects of explosives has been discussed, concluded saying that, Essential techniques for increasing the capacity of a building to provide protection against explosive effects must be developed both inarchitectural and structural approach.ManmohanDassGoel [2] discussed on various strategies of blast mitigation, mainly include to increase the standoff distance, as blast pressure decays very rapidly with the distance. Duo Zhang et,al [3] concluded that sacrificial blast wall provides a better solution and can be adopted or designed against an explosive induced threat and blast-induced threats against a structure should be included in planning and design stages of structural components. Liu (2009) modeled the Subway tunnels under explosive load using FEM, CONWEP module was used for explosive load. The analysis performed not considering the high strain rate behavior of soils under explosive loading. S.V.Chaudhari [4] modeled a 3D model of concrete cube is prepared using smeared crack model and concrete damage plasticity approach, then validation of the model to the desired behavior under monotonic loading. Values of stress obtained was closing matching to each other. Tomasz Jankowiak [5] showed a proper route for to prescribe the material parameters concrete damage constitutive model (CDP) which enables a proper definition of the failure mechanisms in concrete elements. He concluded saying CDP can be used to model the behavior of concrete and the reinforced concrete structures and the other pre-stressed concrete structures in advanced states of loadings.

By undergoing a thorough literature review we can conclude that very less effort have been made to analyze the structural components for blast loading. Specific objective of this paper is to analyze and understand the behavior ofreinforced concrete columns under blast loading conditions using finite element method. To determine the stress and strain behavior of reinforced concrete beam and column structure under random vibrations using non-linear explicit analysis method. The columns are utmost important and most vulnerable part of the structures as the front face of building experiences peak overpressures due to reflection of an external blast wave. It is very tiresome to analyze the complete structure before understanding the individual units of the structure under blast loading conditions. This paper signifies to result the stress and displacement of RCC column structure by varying its skeletal properties i.e. reinforcement. The work emphasizes to understand the variation of stress and displacement of column under time, by varying the diameter of main reinforcement as 16, 20, 25, 28 and 32 mm also spacing of stirrups as 125, 175, 225 and 275 mm. Further results can be used to find out the bending moments and shear forces in the member.

4. Methodology

A finite element method is best suited technique to obtain an approximate solution to a class of problems governed by elliptic partial differential equations. ABAQUS is a software suite for finite element analysis and computer-aided engineering, originally released in 1978. The Abaqus product suite consists of five core software products. The one which is used here is Abaqus/Explicit, a special-purpose Finite-Element analyzer that employs explicit integration scheme to solve highly nonlinear systems with many complex contacts under transient loads.

A. Finite Element Simulation

The simulation involves modelling of reinforced column element, where main bars and stirrups are modelled initially which is reinforced with concrete as shown in fig-2, further proper boundary conditions were assigned. Material properties, elasticity, poisson’s ratio and nonlinear plastic law to the elastic material (e.g. consider the case of an elastic perfectly plastic Von-mises type material model) is assigned to the members. Special properties like Concrete damage plasticity (CDP) constitutive model [6] properties were assigned in concrete compression damage by providing stress and strain values for the required concrete characteristic strength. The aim CDP is to obtain a model, which describes the important characteristics of the failure process of concrete subjected to multiaxial loading. Concrete tension damage property (Bischoff and Perry 1991).) is assigned determining the tension stress and corresponding strain values and yield stress and corresponding cracking strain values. Elastic perfectively plastic behavior for the steel is assigned in the material module and the model is meshed.Interaction of load and member is assigned as Conwep model [7] providing airblast and suitable standoff distance for the TNT blast, finally analysis is run to obtain the maximum displacement and stresses with respect to time period as shown in fig-3.

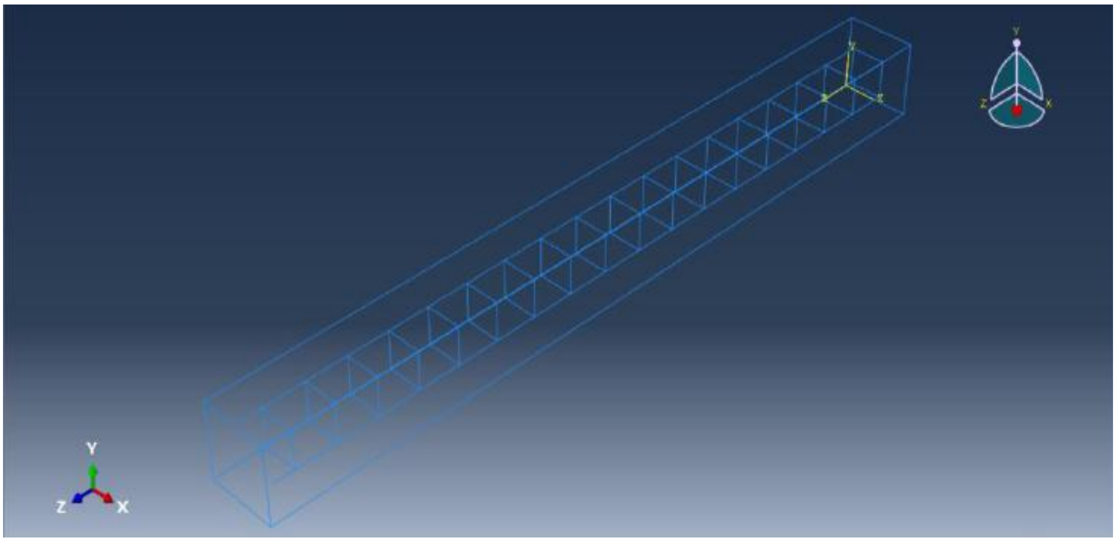
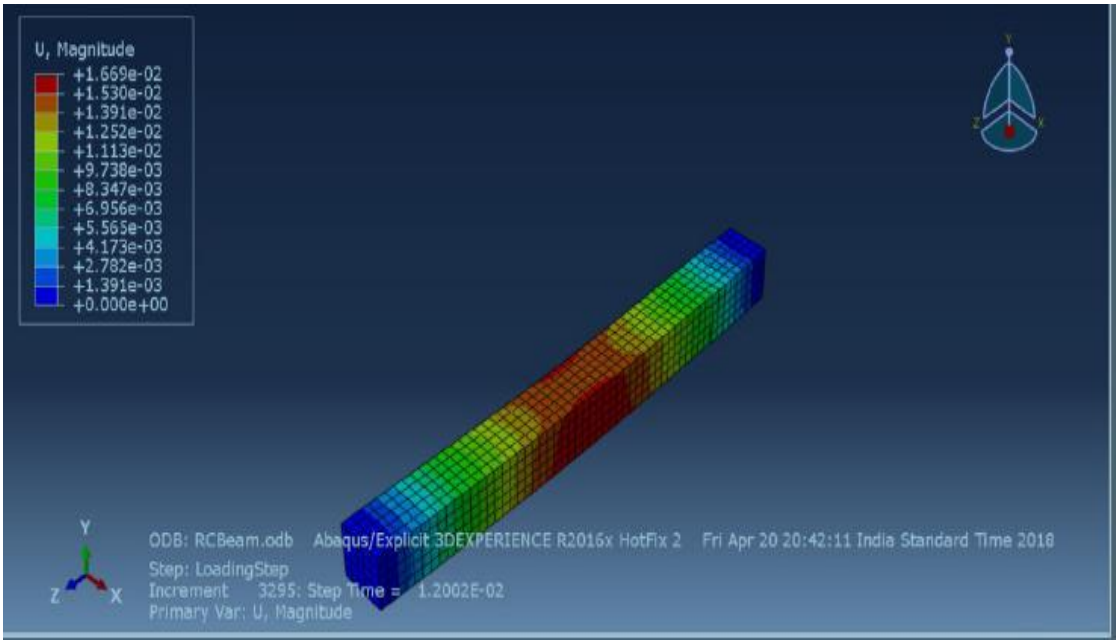


Fig.2. Assembly Model (Wired View)



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ODB: RCBeam.odb    Abaqus/Explicit 3DEXPERIENCE R2016x HotFix 2    Fri Apr 20 20:42:11 India Standard Time 2018
Step: LoadingStep
Increment     3295: Step Time =    1.2002E-02
Primary Var: U, Magnitude
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Fig.3. Showing the beam displacement at step time 1.2002E-02

B.Validation of Finite Element Analysis

To ensure the validity of the numerical simulation, the results of beam deflection of an experimental RC beam under close-in blast loading [8] has been compared with the simulated result using FE software ABAQUS. Experimental investigation emprise on scaling of RC Beam under close-in blast load , to study of damage modes and damage levels of RC beams under different blast loads and to study of dynamic response of RC Beams. The experimental procedure consists of testing of 8 beams of varying dimensions, mass of TNT, standoff distance and scaled distance. Beam displacement is determined by keeping a long needle inside fine sand covered by pinholes below the experimental beams. For our validation a single beam no B2-2 was considered whose displacement was already determined. FEM modeling was done using software ABAQUS as shown in above fig-2. Concrete damage plasticity (CDP) model for unconfined concrete compression values for the grade of concrete is calculated as shown in the fig-4a. The value of yield stress to the inelastic strain of concrete is calculated is as shown in fig-4b [9]. Further tension behavior concrete is assigned as shown in fig-4c and yield stress and cracking strain value is calculated using eqn-03 is as shown in fig-4d. Nonlinear steel behavior is taken as elastic-perfectly plastic model, where it doesn’t account for stain hardening the stress increases linearly until the yield strength is reached, and then the material offers no further resistance to deformation, as shown in fig-5. From the experimental analysis the maximum displacement observed in the B2-2 is 25 mm; our simulation result gave a maximum displacement 17 mm which is very close to the experimental results. The analysis result is as shown in the fig-6.

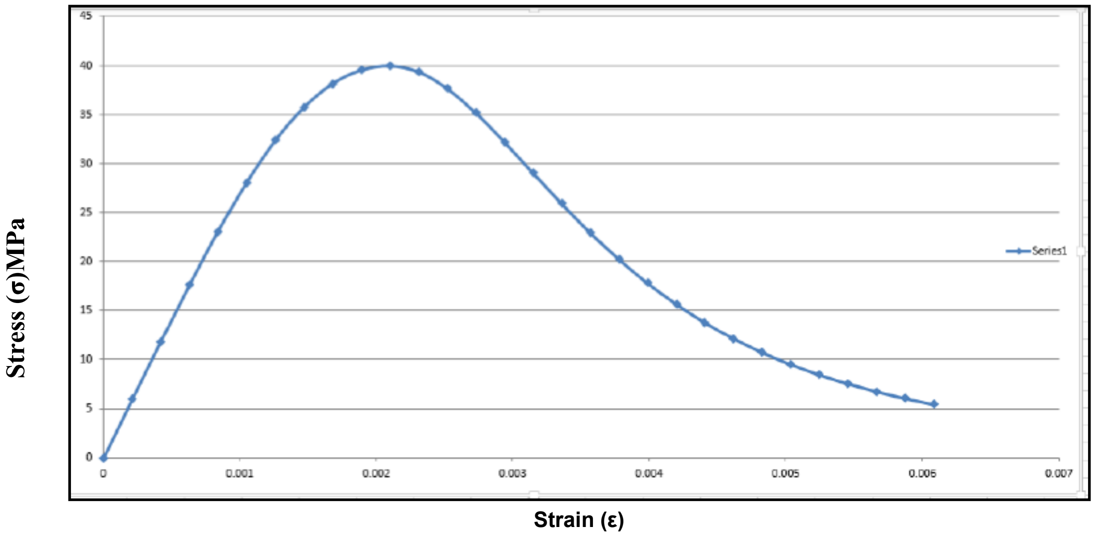

Fig.4a. Compression Stress-Strain Model of concrete

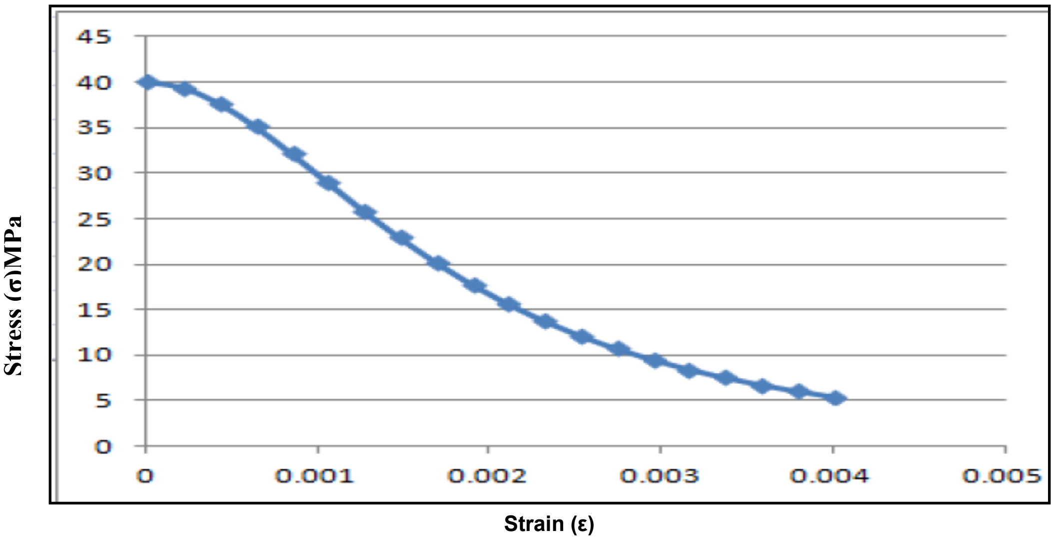

Fig. 4b. Yield Stress v/s Inelastic Strain of concrete

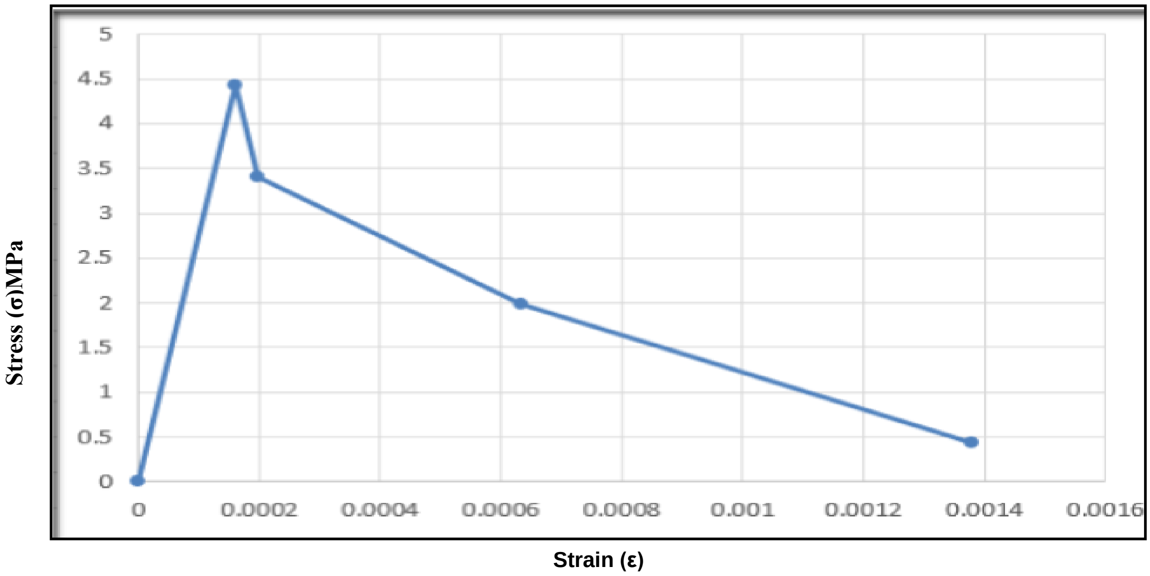

Fig. 4c. Tension Stress-Strain Model of concrete

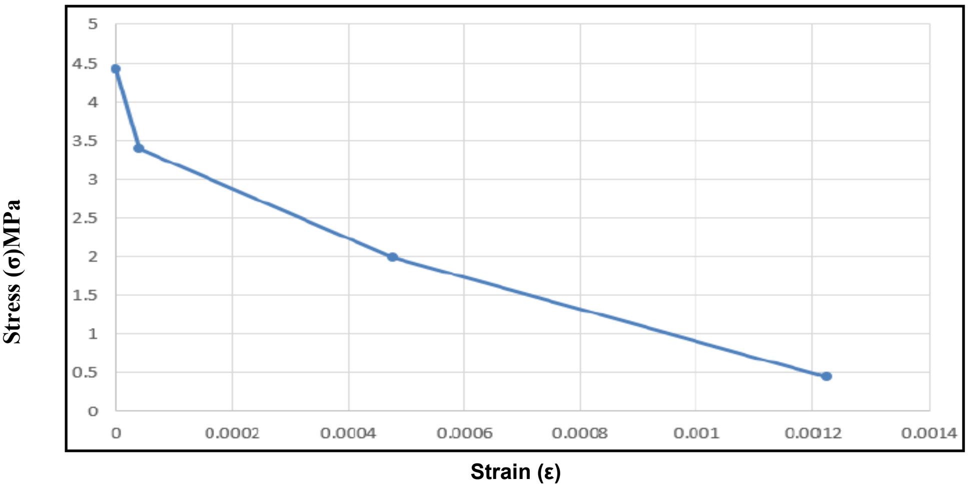

Fig. 4d. Yield Stress v/s Cracking Strain of concrete

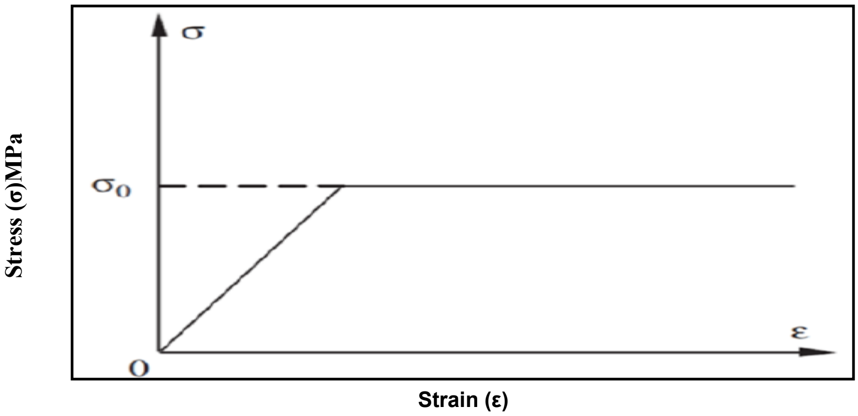

Fig. 5. Stress-Strain for Elastic-Perfectly Plastic for Steel

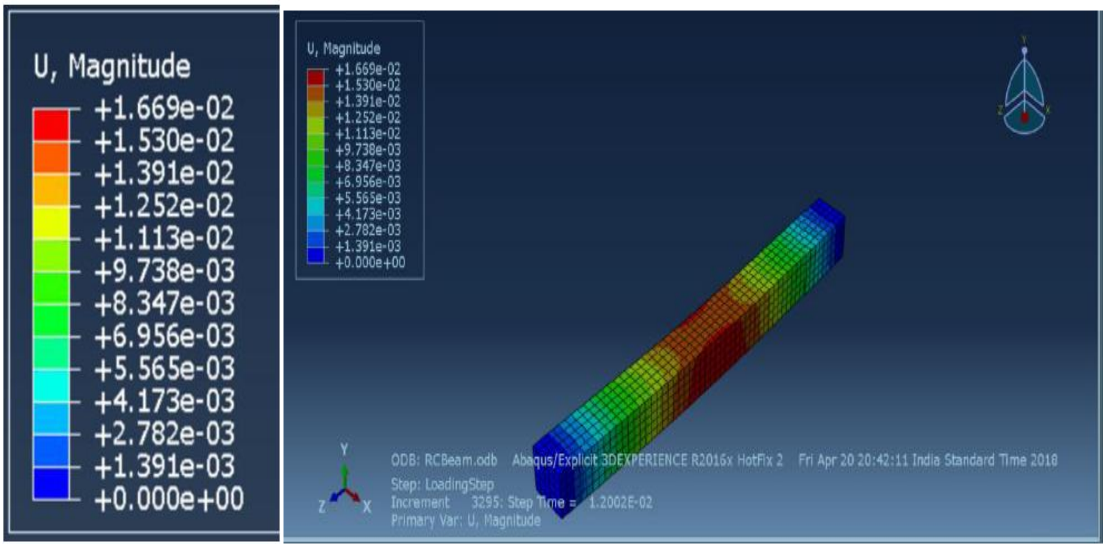

Fig 6. Deflection of Beam B2-2.

5. Parametric Studies

Parametric studies include analysis of RCC columns for constant dimensions, varying the skeletons, i.e. diameter of main reinforcement and diameter and spacing of the stirrups/ties. Efforts have made to draw a comparison of maximum stress and displacement values with respect to step time. Probable conclusions were also drawn from the variation curves are as follows.

A. Variation of diameter of main reinforcement

Here for the dimension of the column taken is width as 300mm, depth as 500mm and length as 3450 mm, 4 no of reinforcement at corners, whose diameter of the main reinforcement varies from 16mm, 20mm 25mm, 28mm and 32mm. Diameter of stirrups taken is 8mm spaced at 125mm c/c. Clear concrete covered is taken 40 mm, a common standoff distance of 0.4m and 0.45 kg mass of TNT is assigned at the bottom of the column in each parametric study. Variation in stress values at increasing step time of impact as shown in fig-7a.

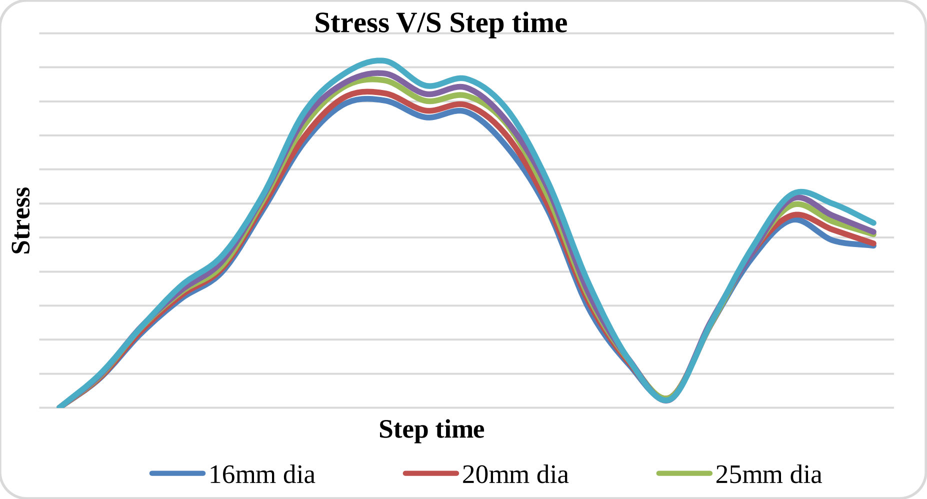

Fig. 7a. Stress variation v/s Increasing Step time

From the above figure we can conclude the with an increase diameter of main reinforcement from 16 to 32 mm, the resistive stress generated within the column structures increases. For 16, 20, 25, 38 and 32 mm diameter the maximum stress generated in 451.352, 462.165, 480.981, 491.306 and 509.604N/mm^2 respectively for a step time of 4.00E-03,shown in fig-7c. Since the blast force is a sudden cyclic wave, the beam generate residual stresses, which goes on decreases in the next cycle.Fig- 7b shows variation of displacement values at increasing step time.

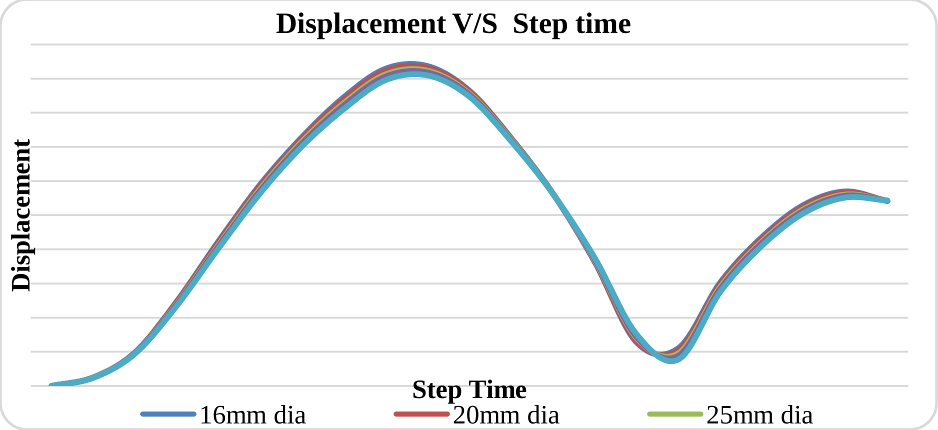

Fig. 7b. Displacement variation v/s Increasing step time

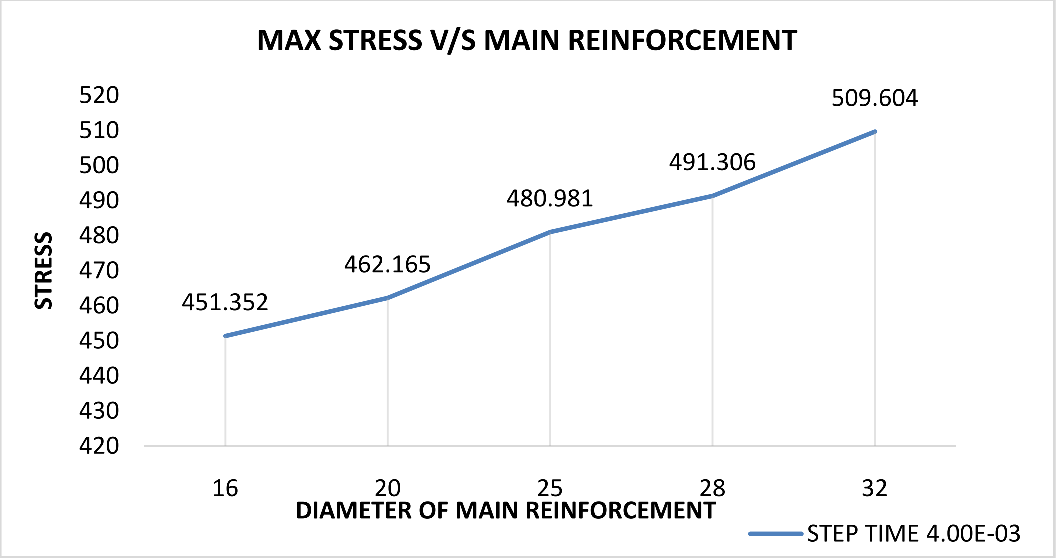

Fig. 7c. Maximum stress v/s diameter of main reinforcement

With an increase in diameter of main reinforcement from 16 to 32 mm displacement decreases. For 16, 20, 25, 38 and 32 mm diameter the maximum displacement generated is 37.4786, 37.2606, 36.9251, 36.7002 and 36.3689 respectively for a step time of 4.50E-03, as shown in fig-7d. Further the beam undergoes residual deflection as shown in the figure 7a.

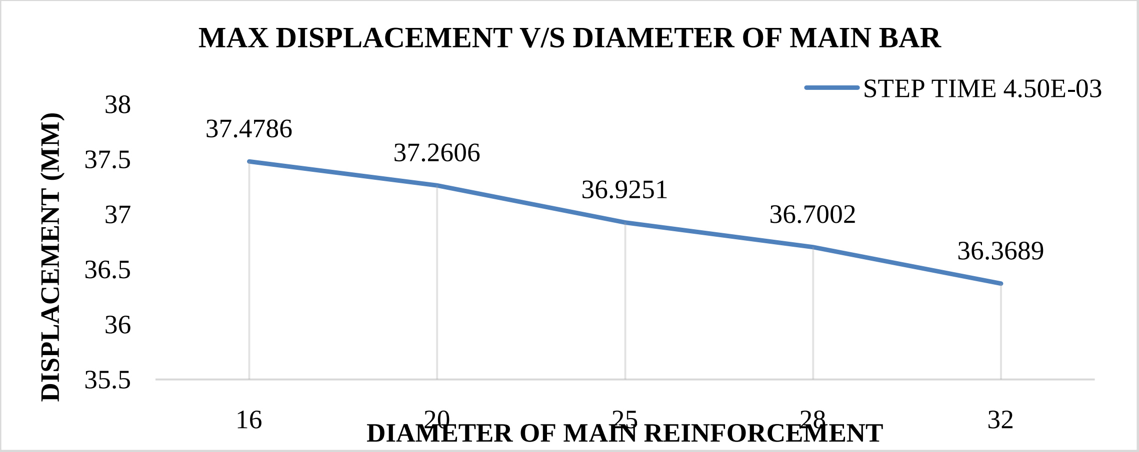

Fig. 7d. Maximum displacement v/s diameter of main reinforcement

B. Variation of stirrups spacing.

Here variation of stress and displacement with the variation of stirrups/ties spacing is studied, the diameter of stirrup is taken constant as 8mm but the center to center spacing is varied as 125mm, 175mm, 225mm and 275mm. The properties and loading conditions are taken same as above, but the diameter of main reinforcement was taken as 16mm. Fig-8a shows the maximum stress generated with respect to variation of spacing and fig-8b shows the maximum displacement with respect to variation of spacing.

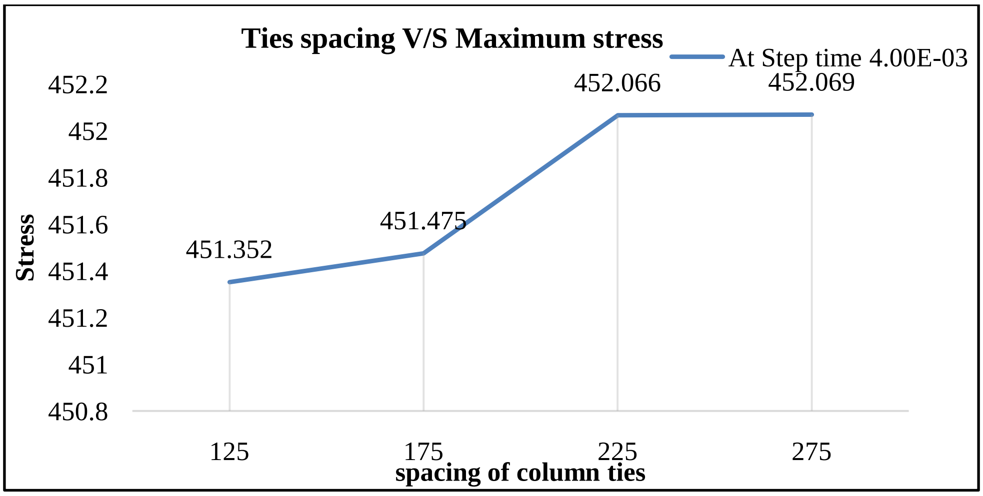

Fig 8a. Maximum stress v/s ties spacing.

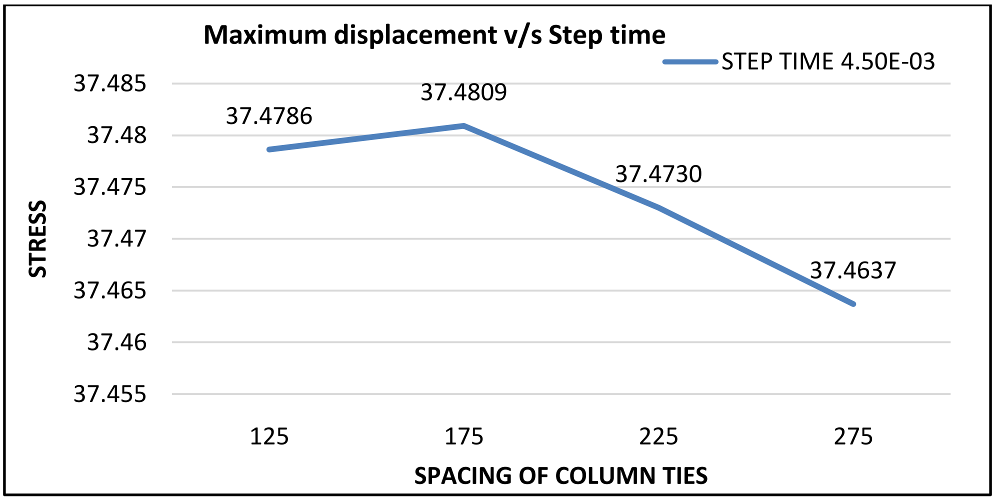

Fig 8b. Maximum displacement v/s ties spacing.

From the variation of stress with respect to stirrups spacing we can conclude that, stress developed with a close spacing is less in comparison with maximum spacing. Even though the variation is very less, but the percentage of variation is more. The graph gradually increases as the spacing of stirrups is more than 200mm further it stays constant up to 275mmspacing.From the variation of maximum displacement with respect to tie spacing we can say that with the closer stirrups spacing beam undergo more displacement compared to maximum spacing. It is also identified that the displacement curve is smoother in case of spacing up to 175mm, after 200 mm the curve is not so much smooth, maximum displacement and smoother curve indicate the ductile behavior of the member, even though the variation is very less, still we can conclude column with closer spaced ties behave ductile in compare to freely spaced member.

6. Conclusion

In this paper RCC columns are analyzed for blast loading condition using a Finite element software ABAQUS, the work aims to investigate the behavior of column under variation of its skeletal components i.e. reinforcements. Despite the fact that, the magnitude of the explosion and the loads caused by it cannot be anticipated perfectly, the most possible scenarios will let to find the necessary engineering and architectural solutions for it. Following conclusion can be drawn from the above work.

1. Even though the analysis of structure under blast loading is complicated, finite element method and software helps us to produce reliable results.
2. Column with proper combination of main reinforcement and properly spaced ties undergo less stresses distribution on the structure and deformations under blast load.
3. By increasing the diameter of main reinforcement, column can achieve resistance towards lateral load and deformation.
4. The significance of providing less confined ties in the columns would contribute lateral load resistance increasing ductility to the column to deformation and producing less stress.
5. It is recommended to provide ties in the column not more than 200 mm to resist blast loading.
6. Supporting the above statement, variation of maximum displacement with ties spacing (Fig 8a and 8b) would suggest that close spaced stirrups enhances its ductility providing maximum displacement compared to maximum spacing.

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