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Comparative Study on the Dynamic Analysis of Blast Loaded Concrete and Steel Structure

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Comparative Study on the Dynamic Analysis of Blast Loaded Concrete and Steel Structure

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Abstract- The terrorist attack on buildings or in its surrounding has increased steadily in recent years. Usually, the blast might occur in the ground level thus columns in ground-level undergo impact loading. Since steel and composite type of columns are used nowadays, the nonlinear dynamic analysis of blast loading in such columns has become highly important. This helps to understand the impact of explosions on columns. In this study, RC column, steel and composite column with equal height are designed for the same load-carrying capacity and Finite Element Modeling using ABAQUS. Time History Method is used to analyze the columns. This study aims to simulate and compare the non-linear dynamic analysis of blast loaded concrete and steel structures. The examination of the result exposes the vulnerability in the steel column and the effectiveness of the composite column. RDX of charge weight 100 kg and standoff distance of 1 meter is considered for analysis. **Keywords** Explosives, Blast Loading, Steel Column, Composite Column, Time History Analysis.

1. Introduction

Day by day the terrorist attack is raised significantly. The intensity of blast is dependent on the sort of explosive used, charge weight of the explosive and the standoff distance. Mostly the standoff distance plays an important role in the propagation of blast wave and charge weight of the explosive influences in the generation of blast waves. This blast wave causes a very large intensity of loading within an extremely quick duration of time and such waves are called as an impulsive load [1]. Such impulsive load makes the structure to vibrate. During vibration, the structure develops a significant number of inertia forces and a significant amount of mechanical energy is stored as kinetic energy [2]. The impulsive load comes under the Non-periodic loading in which the loading does not exhibit the same time variation successively. Usually, these explosions might occur in the ground level or surface explosions. In this surface explosions, the column of the building undergoes impulsive loading [3]. Since steel and composite columns are widely used nowadays, understanding the behavior of such columns to impulsive loading becomes important. Thus, columns shall be analyzed for the nonlinear dynamic analysis. In this paper, three different columns are selected for the performance evaluation namely steel column, normal reinforced concrete column, and composite column. These columns are initially designed for the same load-carrying capacity. These columns are studied for FEM using ABAQUS software. Time history method is carried out for analysis. The charge weight and standoff distance are kept constant during the study to compare and evaluate the performance of the columns under impulsive loading.

2. Literature Review

Weggel (2010) discussed about the various types of chemicals that is used for blast and their impact on the structure [4]. Also, the calculation of the blast load, reflected pressures, View/measure shock front shape and propagation, Dynamic displacements, Dynamic support reactions, structural performances etc. Rutner (2010) analysed the load bearing compression member subjected to a less standoff distance blast from the vehicle [5] and concluded that encasing the concrete in the columns with steel sections and converting them into composite columns significantly improves the blast resistance of the columns. Mougeotte (2010) developed latest evaluation method for executing blast load analysis using the new Coupled Eulerian-Lagrangian (CEL) capability in Abaqus/Explicit [6]. This suggests close to the structure with a body of air (Eulerian), subjected to a pressure wave as a boundary condition, and making it propagate into the Lagrangian structure.

Figulia et al. (2017) reported the actual experimental observations for blast load are assessed and compared with both SDOF and FE models carried out in ABAQUS [7]. The assessment of constructional system which consists of steel rolled beams with two different type of cross sections (HEB100 and IPE120). The Time History method is used to analyze the structure in ABAQUS. Analytical SDOF calculations and FE numerical predictions have been then proposed for some selected test specimens, aiming to compare maximum experimentally observed strains and accelerations. Mishra et al. (2018) conclude the study founded on the examines of different researchers on blast loading performance, various conclusions have been drawn like standoff distance increases the magnitude of blast pressure increases, Blast pressure and blast scaled distance is inversely proportional etc., The study will help to better understand the behavior of RC framed structures during explosive events [8].

3. Methodology

The chief parameters for dynamic analysis for structure are load carrying capacity, ductility, stiffness, cross sectional area, length, steel section and mass. To determine the response of the columns to the impulsive loading, Time History Method is carried out in ABAQUS. According to IS 456: 2000 and IS 800: 2007 the design parameters for reinforced concrete and steel column are considered, respectively. All these columns are designed for same load carrying capacity and design data are obtained RC column, Steel column and composite column. The end condition is taken as fixed for all columns. The length is kept constant throughout the design. Hot-rolled steel section is encased I the concrete section is used as composite column. In composite column, together the steel and concrete would withstand the peripheral blast pressure by intermingling simultaneously by bond and friction [9]. Additional rebars in the concrete prevents spalling of concrete when column under blast loading. For the nature of explosive and nature of the blast, RDX and surface blast is selected. The explosion of the bomb generates the shock waves as pressure. Using the charge weight and standoff distance the blast pressure i.e. impulsive intensity is calculated. The appropriate duration of blast is selected for the time history and graph plotted. At first, all three columns are modelled in the ABAQUS. For the analysis, Dynamic Explicit type is selected. To check and compare the performance of all columns, the load carrying capacity and height are kept as constant. The stresses and displacements along z and y axis are compared for all columns.

4. Design of Columns

In this study, plane RC column, steel and composite column are considered. The length of column is selected as 5 meters. The axial load is taken as 1000 kN. For RC column, area of the steel is assumed as 3% of gross area and design is carried out. The design of compression members is based on the forces and moments that acts in the column. For steel column, design is carried out using IS 800 2007 [10]. ISHB 450 is selected as column. For composite column, all structural steels used shall, before fabrication conform to IS: 2062- 1992 [11] and IS: 8500-1977 [12] as appropriate. Some of the structural steel grade commonly used in construction as per IS: 961-1975 [13] and IS: 1977-1975 [14].

ISHB 450 is selected as the steel section and design is carried out [15]. The design details are mentioned in Figure 1,2&3. The material and sectional properties of the column is given in Table 1 and Figures 1-3, respectively.

Table 1- Material Properties for Column.

TYPE	f_{ck} MPa	f_y MPa	E_s GPa	μ
RC Column	30	415	210	0.15&0.3
Steel Column	-	250	210	0.3
Composite Column	30	415	210	0.15&0.30

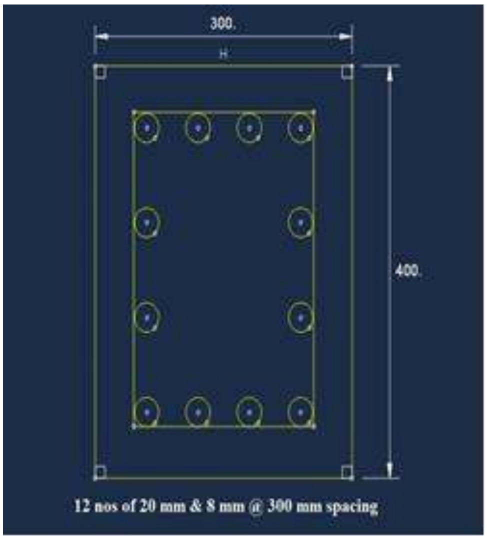

Figure 1 - C/S Details of RC Column.

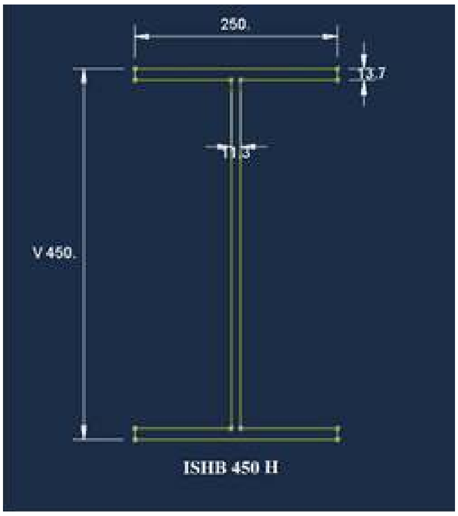

Figure 2 - C/S Details of Steel Column ISHB 450.

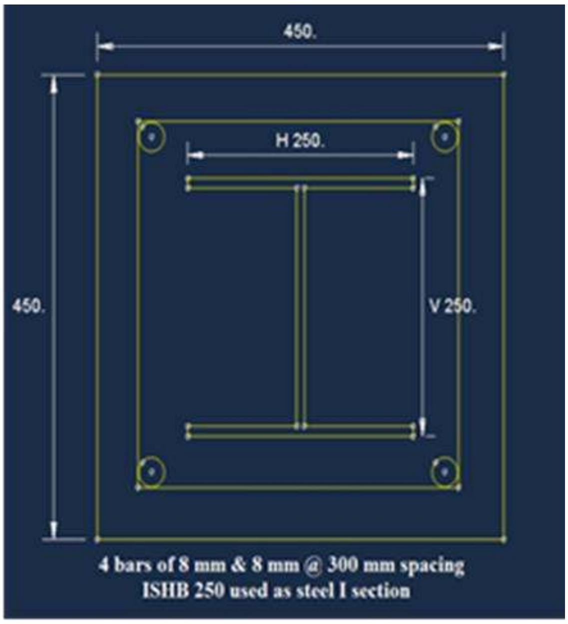

Figure 3 - C/S Details of Composite Column.

5. Model Generation in ABAQUS

The columns are initially sketched for cross sectional area and model is generated for the length. In case of the RC column the breadth and depth are taken as 300*400 mm. Similarly, reinforcement is modelled by selecting the appropriate profile, section, and sectional assignment. Constraint is made in between concrete and reinforcement to act as the single part in analysis. Length is taken as 5 meters. For steel column, rolled steel section ISHB 450 H is modelled as per design. Since there is only single material, there is no constraint. For Composite column, the steps for modelling for steel I section, concrete and reinforcement are same as above. In addition to constraint, interaction shall be made between steel I section and concrete. The coefficient of friction is taken as 0.6 [16]. All model is meshed for the size of 30. The details of the models are shown figure 4 to 12.

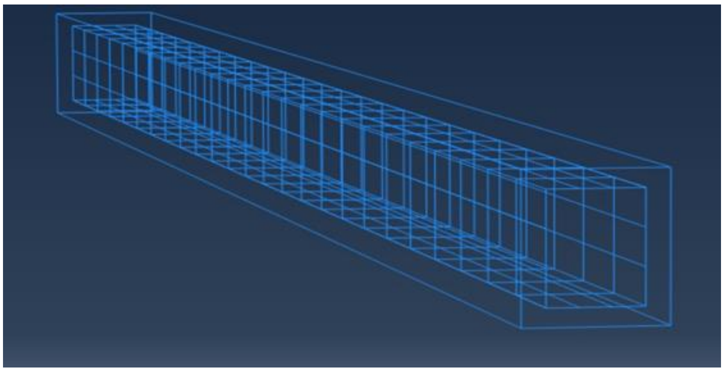

Figure 4 - Model of RC Column with Reinforcement.

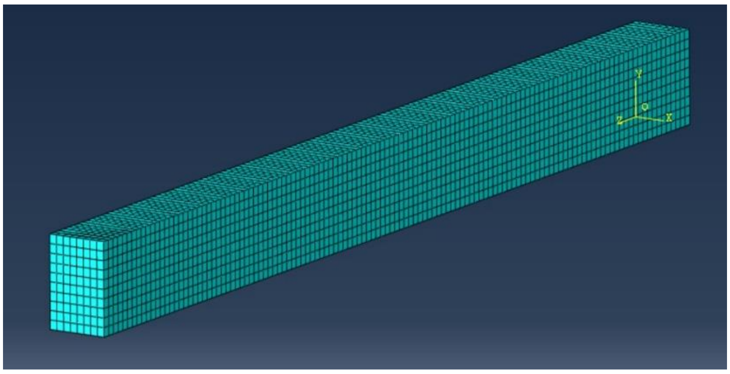

Figure 5 - Meshing of RC Column.

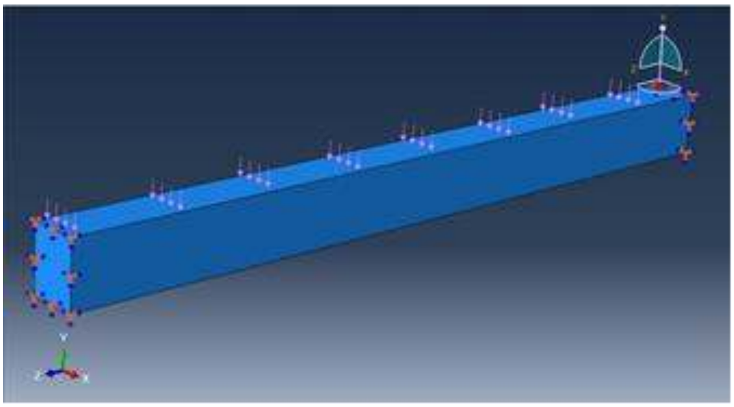

Figure 6 - Loading of RC Column.

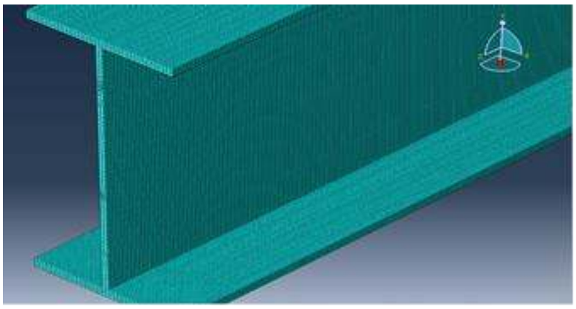

Figure 7- Meshing of Steel Column.

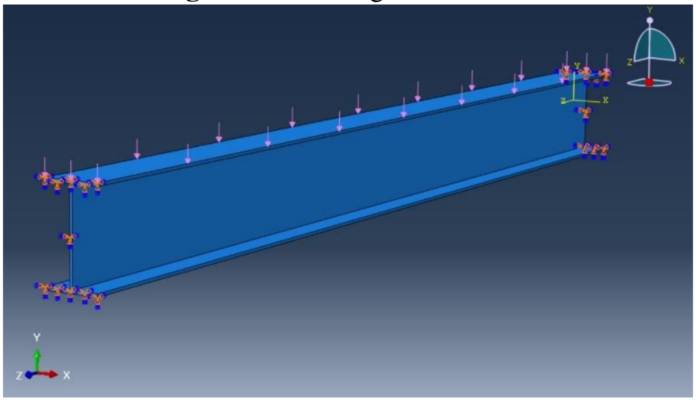

Figure 8 - Model and Loading of Steel Column.

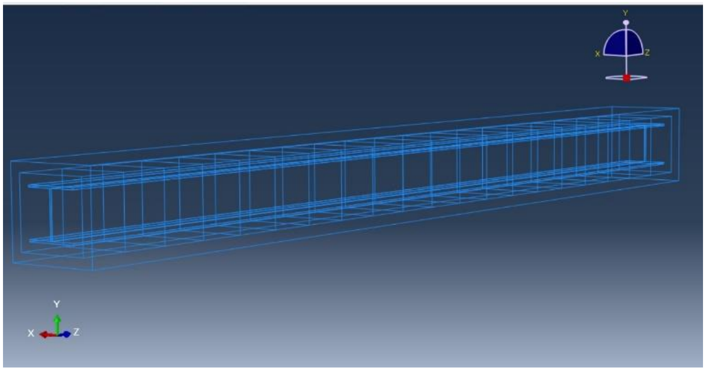

Figure 9 - Composite Column Model.

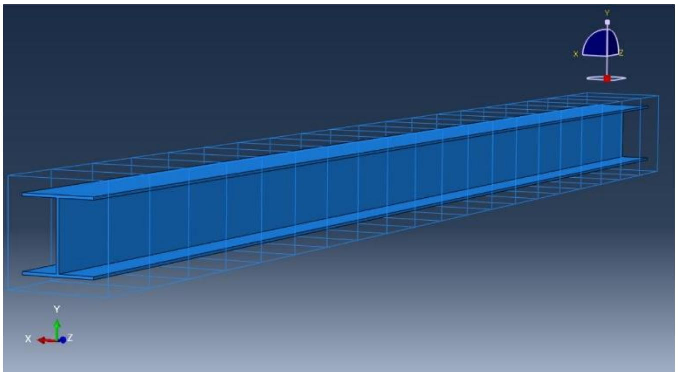

Figure 10 - Steel and Reinforcement in Composite Column.

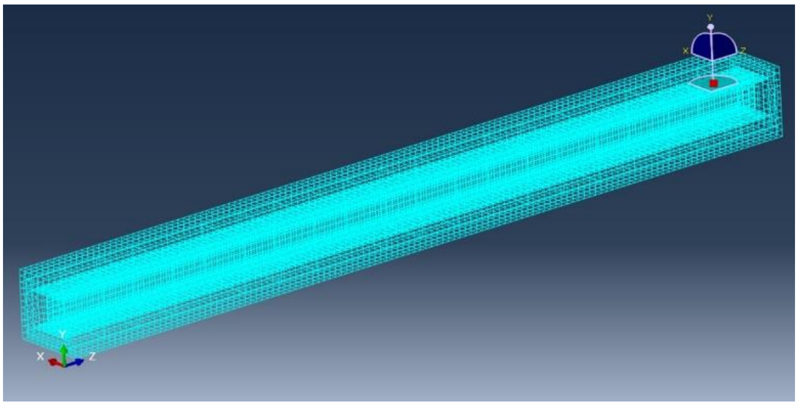

Figure 11 - Meshing of Composite Column.

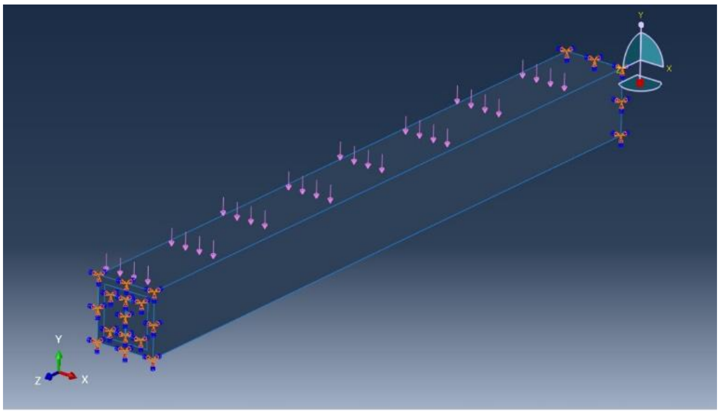

Figure 12 - Loading of Composite Column.

6. Problem Statement

For easier comparison of performance of the models, intensity of loading, height of columns and load carrying capacity of all columns are same and discussed in Table 2. The impulsive loading is dependent of the type of explosive used, charge weight and standoff distance. In this study, RDX type of explosive of 100 kilogram as charge weight is used for analysis. The pressure of the impulsive load is calculated from explosive type, Charge weight of explosive and standoff distance. The pressure is applied in the direction respective to Y-axis for all models.

Table 2- Problem Statement.

Specification	Details
Explosive Type	RDX
Chemical Name	Cyclotrimethylenetrinitramine
Charge Weight	100 kg
Standoff Distance	1 meter
Blast Pressure	18 mPa
Blast Duration	0.01 seconds
Length of column & Boundary Conditions	5 meter and $U_x=U_y=U_z=R_x=R_y=R_z=0$

7. Analysis of Model

Every model is analysed for Time History Method. The Time History graph is taken as triangular. The chief parameters that obtained from the nonlinear dynamic analysis for the performance evaluation of models are stresses and displacements along Z-axis and Y-axis. The details of the time history plot are given in Figure 13.

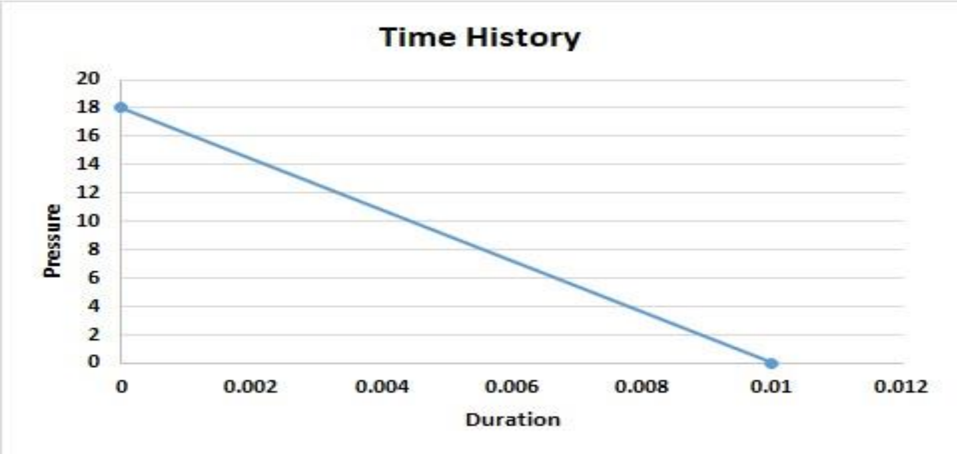

Figure 13 - Time history plot for the blast.

7.1 Stress and Displacement in RC column

Initially, the RC column of size 300*400mm with length 5 meter is subjected to surface blast. The support condition of the RC column is fixed on both sides. The pressure is applied on the y axis direction and analysed. The Figure 14 shows the stress variation in the column. In the outer surface of the column the stress is set to constant. The maximum stress that RC column experiences is 6.88E3 MPa and minimum stress is 10.57 MPa. But at inner core the stress is increasing. Figure 15 & 16 shows the displacement along the U3 and U2 direction, respectively. Maximum and minimum displacements along the extreme compression and tension zones are 24.32 mm and -24.32 mm. At neutral axis, the column undergoes very less displacement. The results are shown in Figure 14 to 16.

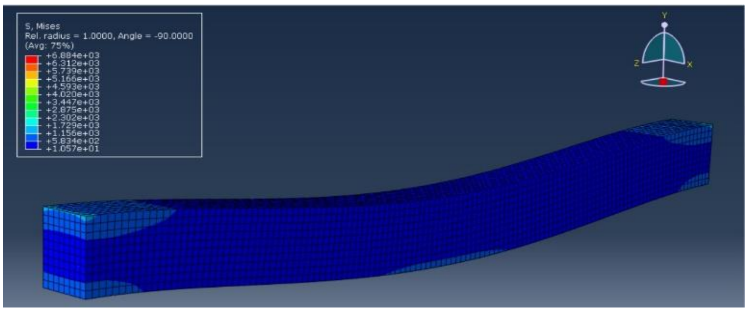

Figure 14 - Stress (MPa) Distribution in RC Column.

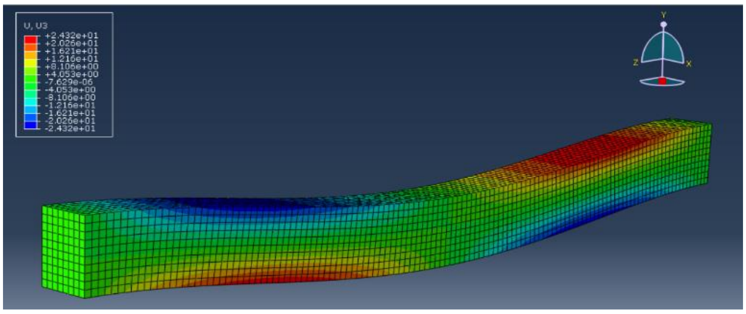

Figure 15 - Displacement (mm) along Z direction.

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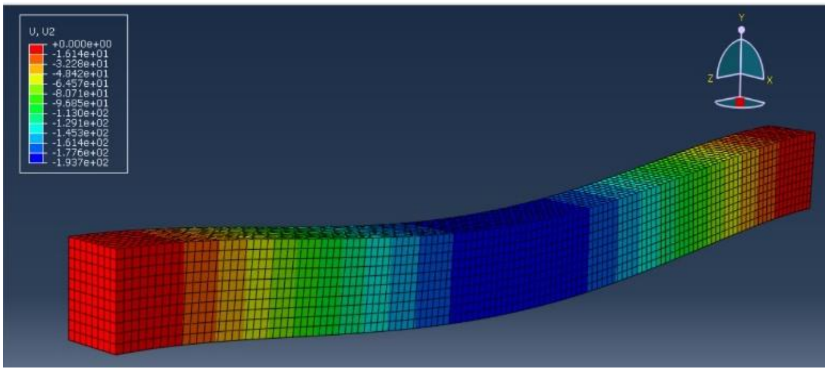

Figure 16 - Displacement (mm) along Y direction.

7.2 Stress and Displacement in steel column

In second part of the model, the steel column of ISHB 450H with length 5 meter is subjected to surface blast. The support condition of the steel column is fixed on both sides. The pressure is applied on the y axis direction and analysed. The figure 17 shows the stress variation in the column. Since there is not any solid mass confinement of steel column during the blast, the steel column experiences wide range of stresses. The maximum stress that steel column experiences is 8.54E3 MPa and minimum stress is 2.06E2 MPa. But in the web at midspan the stress is less compared to extreme section. At one third of the span on either side, flanges undergo less stress. Figure 15 & 16 shows the displacement along the U3 and U2 direction, respectively. Maximum displacement at mid span is found to be -2.06E2 mm. The results are shown in Figure 17 to 19.

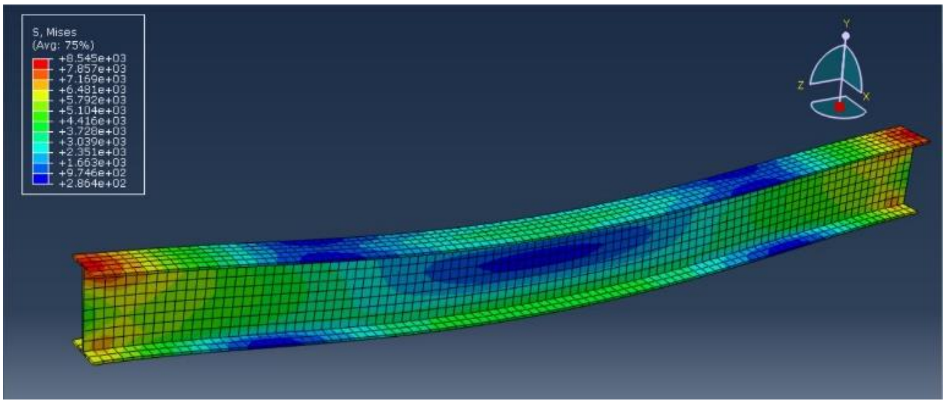

Figure 17 - Stress (MPa) Distribution in steel column.

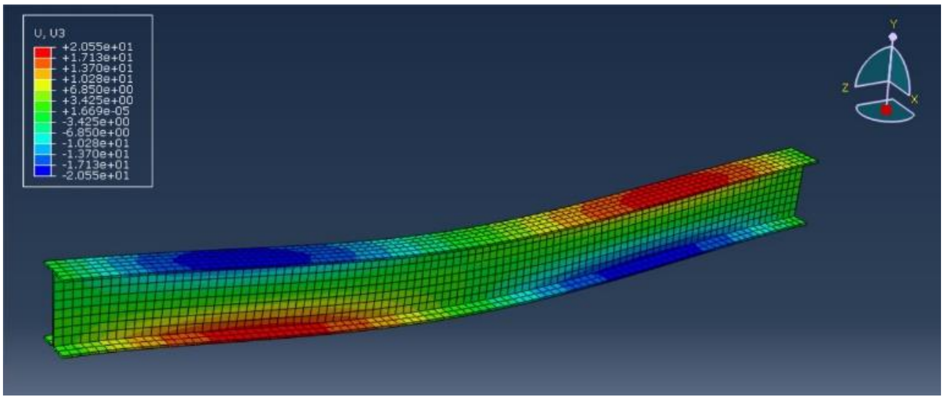

Figure 18 - Displacement (mm) along Z direction.

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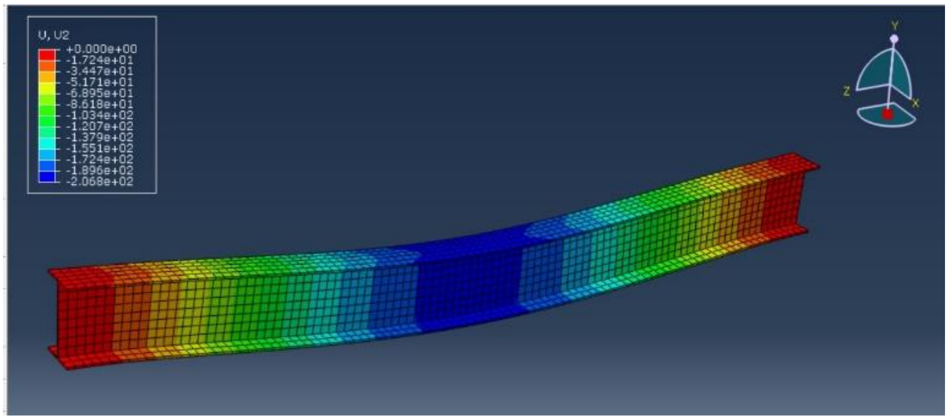

Figure 19 - Displacement (mm) along Y direction.

7.3 Stress and Displacement in composite column

In third part of the model, the steel section of ISHB 250 is encased by reinforced concrete of size 450*450 mm with length 5 meter is subjected to surface blast. The support condition of the steel column is fixed on both sides. The pressure is applied on the y axis direction and analysed. The figure 20&21 shows the stress variation in the composite column. Although there is solid mass confinement of reinforced concrete, the steel section in composite column undergoes wide range of stresses. The stress pattern in steel section is as similar as steel column. But the outer surface of the concrete undergoes constant stress like RC column. The maximum stress that column experiences is 5.62E3 MPa and minimum stress is 3.42 MPa. In the web of steel section at midspan the stress is less compared to extreme section. Figure 22,23,24&25 shows the displacement along the direction U3 and U2 in outer section and steel section, respectively. Maximum displacement at mid span is found to be -2.06E2 mm. The results are shown in Figure 20 to 25

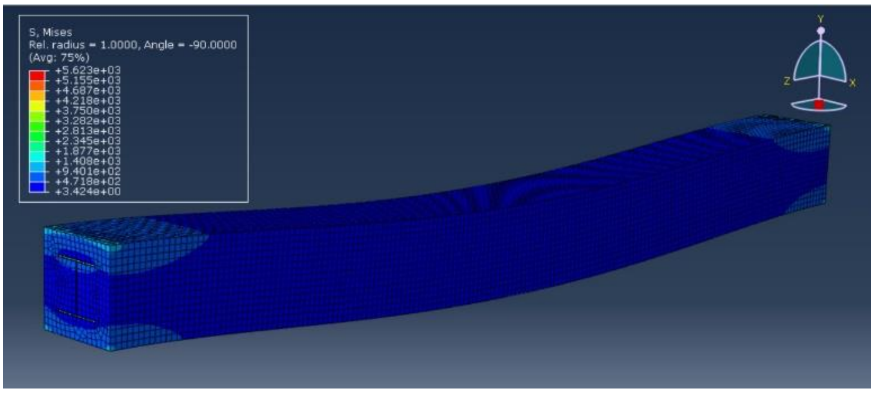

Figure 20 - Stress (MPa) Distribution in composite column.

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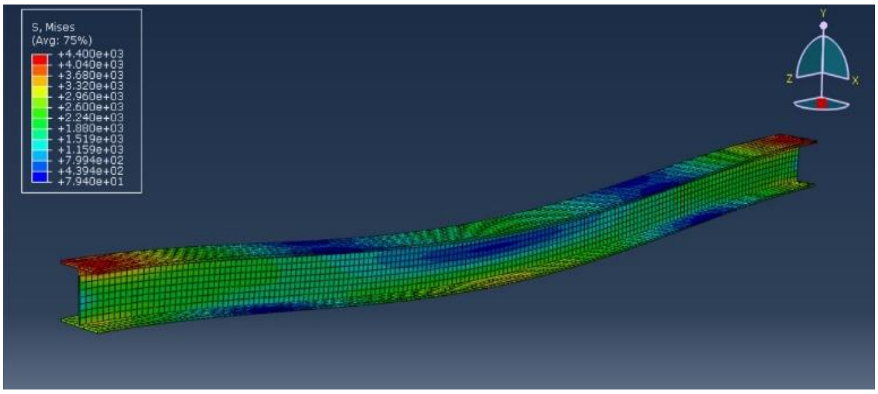

Figure 21 - Stress (MPa) Distribution in steel in composite column.

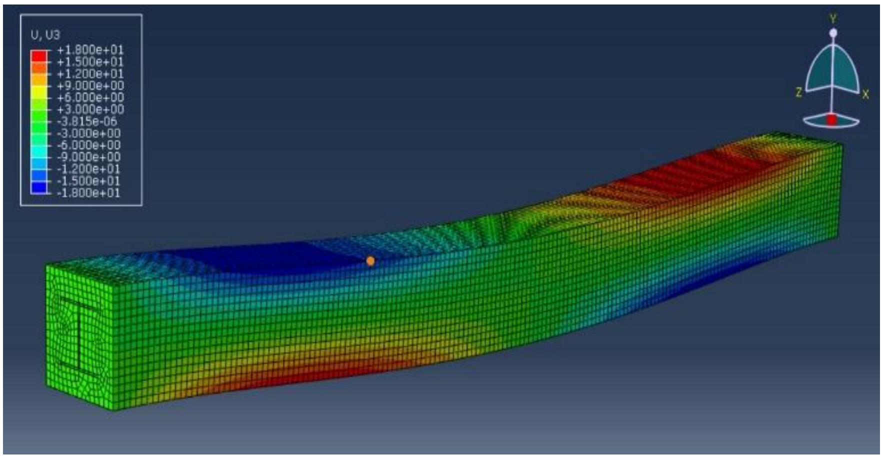

Figure 22 - Displacement (mm) along Z direction.

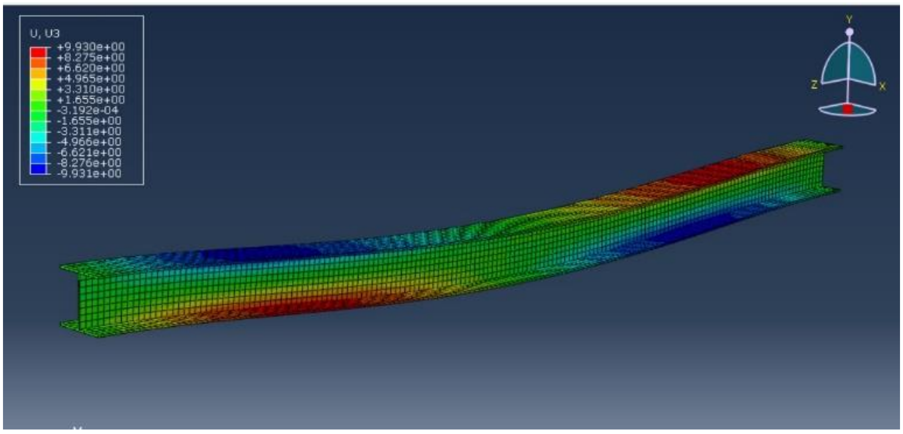

Figure 23 - Displacement (mm) of steel in composite column.

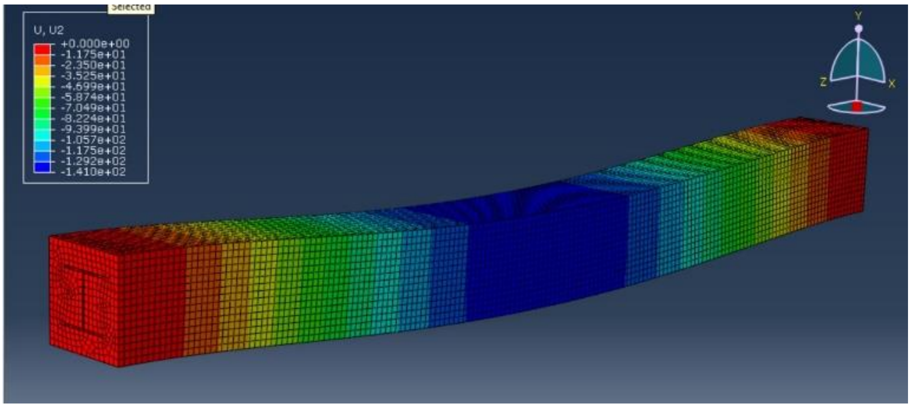

Figure 24 - Displacement (mm) along Y direction.

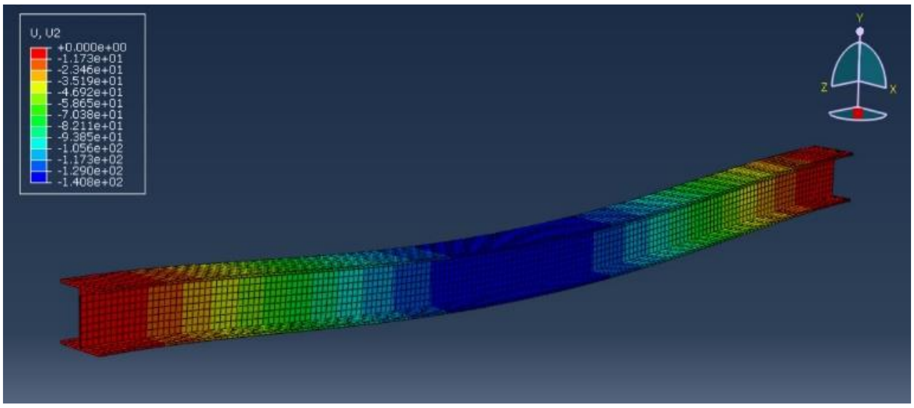

Figure 25 - Displacement (mm) of steel in composite column along Y direction.

8. Results and Discussions

Figure 26 explains the performance of the columns under impulsive loading. By keeping stress as the varying parameter, the performance in each column are evaluated. As we can see from the graph steel column experiences the highest stress. And composite column undergoes less stress. Although all columns are designed for same load, the performance of columns under impulsive loading is different. Since the steel column is exposed to the blast openly without any mass confinement, they undergo large amount of stresses. Figure 27 and 28 gives the displacement along the cross section and the length of the column. In stress graph it was steel with high stresses. But in the figure 27, while compared to the RC column steel undergoes less displacement. Since there is the confinement in the composite column, the steel section undergoes least displacement of all. Figure 28 explains the displacement along the length of the column and steel column undergoes large displacement and composite column undergoes least displacement at mid span.

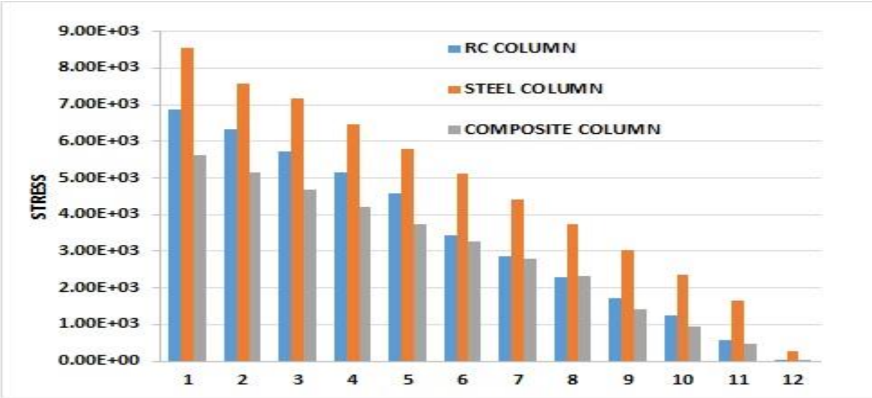

Figure 26 - Comparison of Stresses (MPa) with RC column, Steel Column & Composite Column.

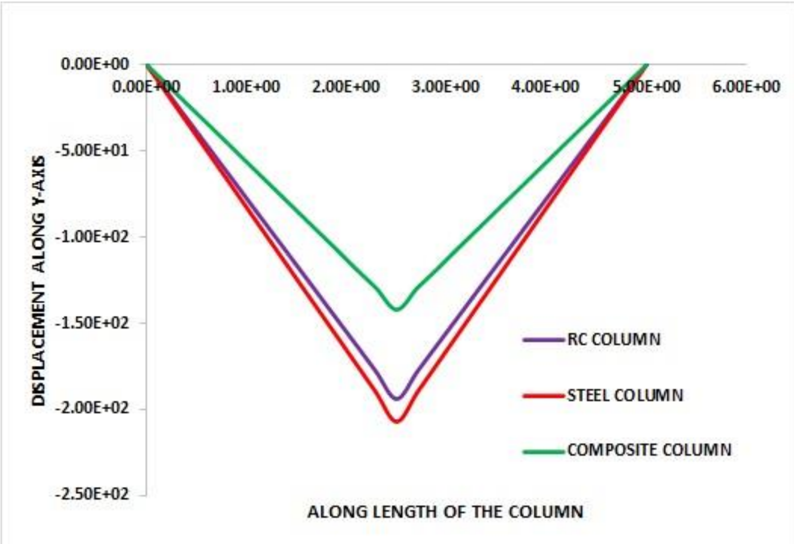

Figure 27 - Comparison of Displacement along C/S with RC column, Steel Column & Composite Column.

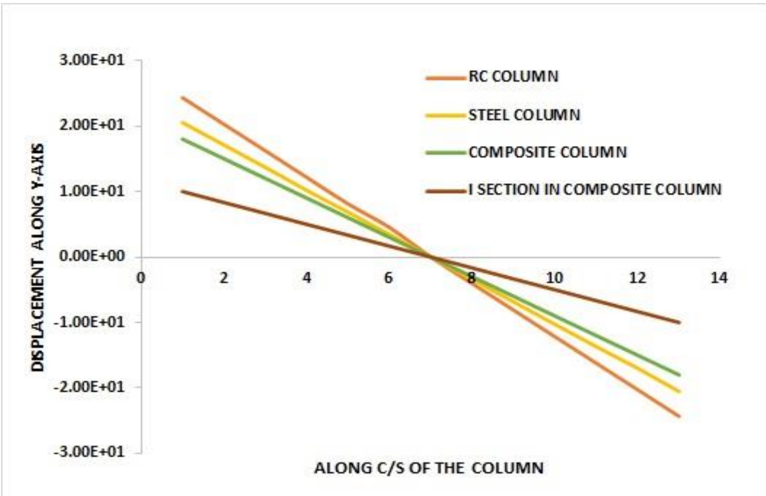

Figure 28 - Comparison of Displacement along Length with RC column, Steel Column & Composite Column.

9. Conclusion

The RC column, steel column & composite column are designed, modelled, and analysed under blast load. The dynamic response for all column models is studied. The support conditions for all models are fixed on both ends. The stress and displacement are carried out. The following conclusions are arrived as

- Comparing the stresses for steel column and RC column to the composite column, the composite column exhibits 51.95% and 22.41% of lesser stress, respectively.
- Comparing the displacements, the percentage change in the displacement in the composite column is 46.66% and 37.37% with steel and RC column.
- Although all columns are designed for same load, the performance of composite column is better than Steel column and RC column.
- The steel structures are vulnerable to the blast attacks.
- Exposing the confined steel section such as composite column to the blast, significantly enhances the performance of column under impulsive load.

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