Numerical Analysis of Reinforced Concrete Column under Free Field Air Blast

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***Abstract*— In India 95% of the Civil Infrastructures is made with Reinforced Concrete (RC) structures. The normal service life period of a Reinforced Concrete structures will be around 50 years[1]. Once the structure reaches its service life period the repair and rehabilitation methods does not keep the building to restore it. To reutilize the land and for the infrastructure development, it is necessary to demolish the aged buildings. Since India is a developing country, the threat towards terrorist's attacks on the civil structures will be more when compared to the other countries. So the research has two perspectives; one is to demolish the aged buildings and another one is to protect the buildings from the terrorist's attacks. In RC structures column is the significant load-bearing element and further exterior columns are probably the most vulnerable structural elements to accidental explosions which is based on strong column weak beam theory concept. In this study the dynamic response of the RC Column is numerically investigated by using finite element software LS DYNA. Parametric studies were chosen to cover a wide range of factors on the global column response. The study concluded that the transverse reinforcing bars confining the core concrete of the RC column significantly affect the damage of the RC column specimens under blasting.**

***Keywords*— Blast, LS-DYNA, Rehabilitation, Strong Column Weak Beam, Charge Weight**

I. INTRODUCTION

Many nations have become victims of terrorism on a grand scale. Bombs have exploded in and around buildings in many countries causing civilian casualties and structural damage. As a result, such events have generated considerable concern over the ability of countries to protect buildings and their occupants from the continued threat of bombings. So far there are 82 terrorist attacks from the year 1984-2016 happened in India. In response to a potential threat of terrorist bombings against civilian structures, various defense agencies and research councils are examining the design methodologies and construction techniques. Protecting the buildings against vehicle bomb attacks has become a priority. The issue of the structural integrity of existing buildings is now a burning one. Analytical, theoretical and design-cum-construction techniques are constantly being reviewed by government agencies and engineering consultants.

A bomb explosion within or around a building can have catastrophic effects, damaging and destroying internal or external portions of the building. It blows out large framework, walls and doors/windows and shuts down the building services. The impact from the blast causes debris, fire and smoke and hence can result in injury and death to occupants. Conventional structures normally are not designed to extreme loading conditions like impact and blast etc. 95% of the civil structures are RC structures which have been proved to be vulnerable under explosion accident. An understanding of the dynamic response of RC components such as Slab, Column and Beam under blast loading is vital in the damage evaluation of RC structures and to make a blast resistant design. Column failure is normally the primary cause of progressive failure in frame structures.

In the present study, numerical investigation is carried out to study the damage mechanisms of RC columns under close-in blast loading. Firstly, the experimental tests in the literature are analyzed. Secondly, the finite element model is calibrated through comparisons of the numerical results with the experimental results reported in the literature. Finally, intensive simulations are carried out to investigate the damage mechanisms of the RC column under close-in blast loading.

A. Objectives

- To understand the basic concepts in effects of structures under blast loading by reviewing the literatures.
- To validate the RC column under free field air blast.
- To do parametric analysis on RC columns under free field air blast.

B. Numerical Model

Finite Element Method (FEM) is a powerful method in analyzing the structures. Here the numerical simulation is done by using the software LS-DYNA. The software is mainly based on explicit numerical model methods and it is used to analyze the problems related with large deformation structure to high velocity impact and blast load.

To ensure the accuracy of the FEM model created using LS-DYNA, numerical results are compared with the experimental results available in literatures.

II. EXPERIMENTAL TEST INTRODUCTIONS

In this study, the experimental tests for RC column conducted by Farouk Siba [5] were used to validate the FE model. The RC Column was 300mm in width, 300mm in depth, 2700 mm height and fixed at one end and pinned at other end. The longitudinal reinforcements were 4 numbers of 19.5mm diameter rebar with the yield strength of 474.4MPa. A 40mm clear cover was provided on the side faces of the column. D11.3 cross ties were arranged with intervals of 300mm, whose yield strength was 474.4MPa. The unconfined compressive strength of the concrete was 41.3MPa, the Young's modulus of longitudinal reinforcements and the cross ties was 210GPa. An explosive charge with 123kg mass Tri Nitro Toluene (TNT) was placed at a distance of 2.6m from the column specimen. The experimental setup is shown in fig. 2 RC frame model was tested by Baylot and Bevins[2] to study the dynamic response of RC column in a two storied RC building. 8kg equivalent of TNT was detonated at a standoff distance of 1.07m in the test.

A. Material model

Material models available in LS-DYNA to model the concrete elements are MAT Johnson Holmquist Concrete (MAT_111), MAT Brittle Damage(MAT_96), MAT Pseudo Tensor(MAT_16), MAT CSCM Concrete(MAT_159) and MAT Concrete Damage Rel3(MAT_72_REL3). In this research material model MAT _72_REl3 is selected based on previous studies. It can be used for concrete subjected to large strain, high strain rates and high pressures. Similarly for steel reinforcement, the material model is MAT Piecewise Linear Plasticity (MAT_024). By using this, both longitudinal as well as transverse reinforcements are modeled. It is an elasto-plastic material with an arbitrary stress versus strain curve and arbitrary strain rate dependency can be defined.

B. Strain rate

Normally the strain rates will range from $10^2 - 10^4\ s^{-1}$ for blast loads. This high strain rate will change the dynamic properties of RC structures. When RC structures are subjected to blast loads, the strength of concrete and reinforcement will increase due to high strain rate effects.

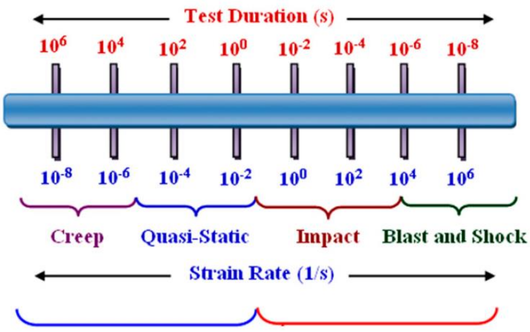

Fig. 1. Strain Rates under different loading

In LS DYNA the strain rate effect is considered for both steel and concrete material models by incorporating the Dynamic Increase Factor (DIF) relationship.

1) Dynamic Increase Factor – Concrete

From [21]

$$CDIF = \frac{f_{cd}}{f_{cs}} = \left[\frac{\varepsilon_d}{\varepsilon_{cs}}\right]^{1.026\alpha} \quad for\ \varepsilon_d < 30s^{-1}$$

$$CDIF = \frac{f_{cd}}{f_{cs}} = \gamma[\varepsilon_d]^{\frac{1}{3}}\ for\ \varepsilon_d > 30s^{-1}$$

$$log\gamma = 6.156\alpha - 0.49$$

$$\alpha = \left[5 + \frac{f_{cu}}{4}\right]^{-1}$$

For example,

Take f_{cu} = 42 MPa and ε_d = 106 (from fig. 1)

α = (5+3(42)/4)-1 α = 0.02739

γ = e(6.15x0.0279– 0.49) γ = 0.725

CDIF = 0.725(106)1/3 CDIF = 72.5

2) Dynamic Increase Factor – Steel Reinforcement

From [21]

$$DIF = \left[\frac{\varepsilon_d}{10^{-4}}\right]^{\alpha}$$

$$\alpha = 0.074 - 0.040\left[\frac{f_y}{414}\right]$$

For example,

Take f_y = 415 MPa and ε_d = 106 (from fig. 1)

$\alpha = 0.074 - 0.040\left[\frac{415}{414}\right]$ α = 0.034

$DIF = \left[\frac{10^6}{10^{-4}}\right]^{0.034}$ DIF = 2.187

C. Validation of FE Model

Here the Finite Element model is validated with the experimental results referred from, "Near-Field Explosion Effects on Reinforced Concrete Columns: An Experimental Investigation", [3].

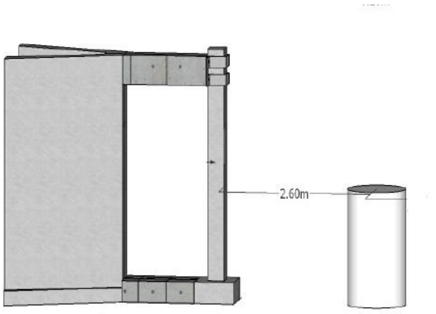

Fig. 2. Experimental Setup of RC Column

In this study, the experimental test was conducted on several RC columns by [3] for examining the dynamic response and effect on structure under close-in blast loading.

In this research one of the each case are considered to validate the modeling technique followed in simulations while predicting the FE capacities. Table 1 show the experimental test matrix of RC column and it is referred to examine the FE model's reliability in analyzing the response.

TABLE I. EXPERIMENTAL TEST MATRIX OF RC COLUMNS

Parameters	**Column I**
Height(mm)	2700
Breadth(mm)	300
Depth(mm)	300
Transverse bar diameter/spacing(mm)	11.3/300
Longitudinal bar diameter(mm)	19.5
Yield strength of steel(Mpa)	474.4
Concrete compression strength(Mpa)	41.3
Charge(equivalent-kg-TNT)	123
Standoff(m)	2.6

The above stated RC columns are modeled in Hyper mesh and analyzed for its dynamic response using LS-DYNA. Here the validation is done using Column I by comparing the maximum deformations undergone during the experiment and FE simulation. Fig. 3 shows the comparison of maximum deformation of RC column from experiment and FE Simulation.

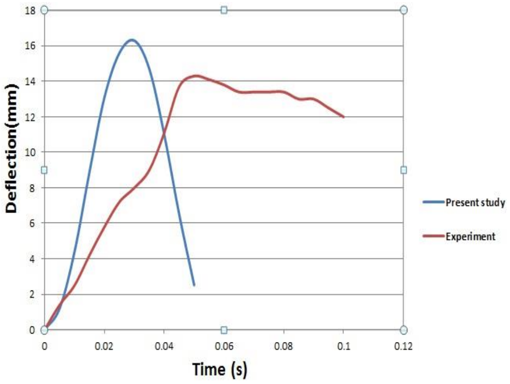

Fig. 3.Comparision of Maximum Deformation from Experiment and FE Simulation

The maximum deformation from experiment was 14.3mm at 5.3ms while the maximum deformation from FE was 16.3mm at 3ms of blast duration. The values are approximately significant. Therefore the modeling technique followed is enough in analyzing the response of structure.

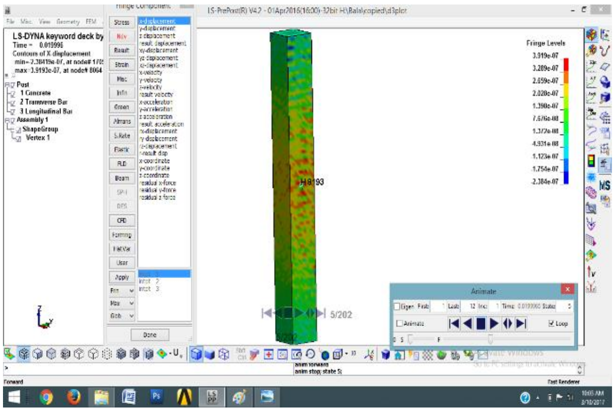

Fig. 4. Fringe pattern showing maximum deformation

D. Parametric study

Shear Reinforcement, Longitudinal Reinforcement, Diameter of Stirrups, Diameter of Longitudinal Bars, Concrete Grade, Standoff distance, Height of the Blast and Charge Weight are said to be the major parameters which have influence on RC Structures while blasting. Among the above mentioned parameters Spacing of transverse bar, Concrete grade and Charge weight are said to be the parameters which having greater influence on RC structures under close-in blast loading. In the present study the following are the parameters which are used for simulation purpose.

TABLE II. PARAMETERS IN CURRENT STUDY

Spacing of Transverse bar(mm)	**Concrete Grade(Mpa)**	**Charge Weight(kg)**
100	M30	75
200	M40	100
300	M50	125
		150
		180

From Table 2, A total of 45 combination are analysed for the afore mentioned parameter. All the 45 combinations are subjected to pre-processing and post-processing methods. Initially, 45 models were created in the hyper mesh software. They are analysed in the LS DYNA and there after stimulated in ANSYS. Finally post-processing was done by LS DYNA. The following are the results which are obtained by using LS DYNA.

TABLE III. DETAILS OF COLUMN SPECIMEN

Column No.	**Spacing of Transverse bar(mm)**	**Concrete Grade(MPa)**	**Charge weight(kg)**
C1	300	M40	75
C2	300	M40	100
C3	300	M40	125
C4	300	M40	150
C5	300	M40	180

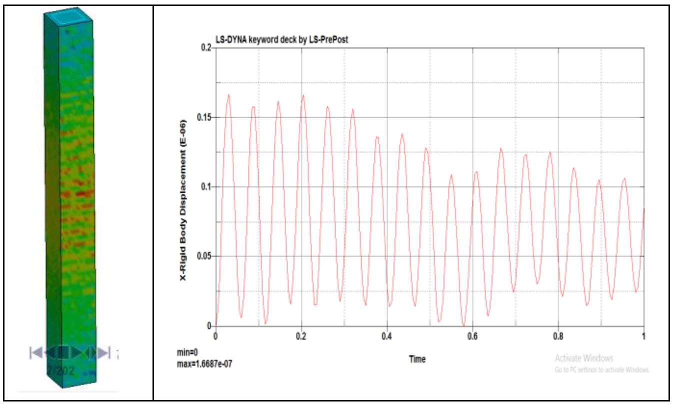

Fig. 5. C1 Deformation Pattern

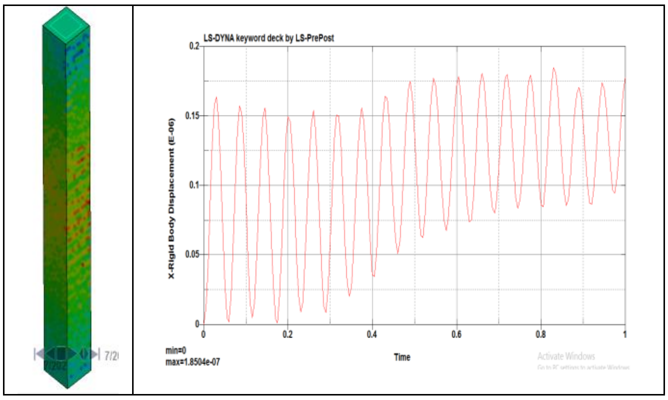

Fig. 6. C2 Deformation Pattern

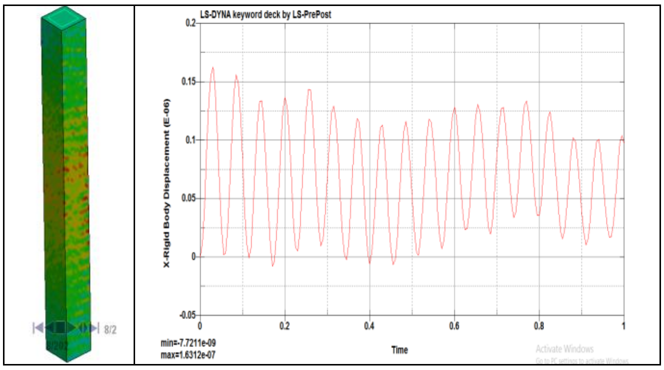

Fig. 7. C3 Deformation Pattern

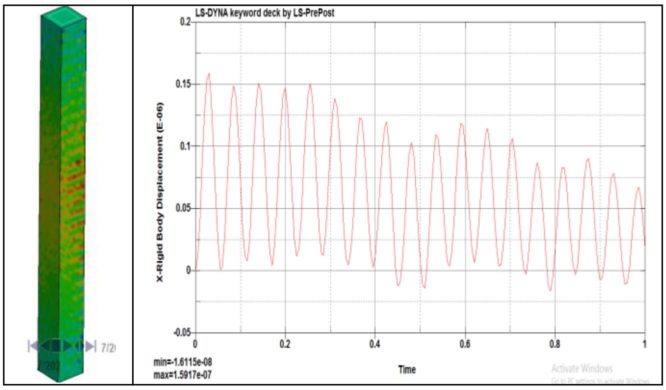

Fig. 8. C4 Deformation Pattern

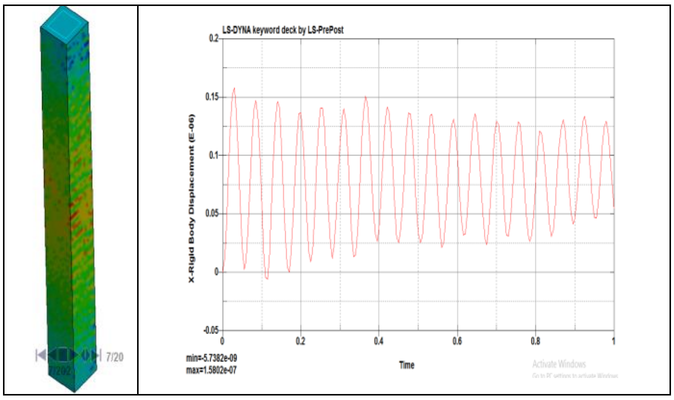

Fig. 9. C5 Deformation Pattern

E. Effect on grade of concrete:

The grade of concrete has an effect on the displacement of column. Increase in the grade of concrete decreases the displacement correspondingly. A total of three grades of concrete namely M30, M40 and M50 were implemented for the analysis and from the results it was evident that M50 grade of concrete had more restraint to the displacement comparatively to the M30 grade of concrete.

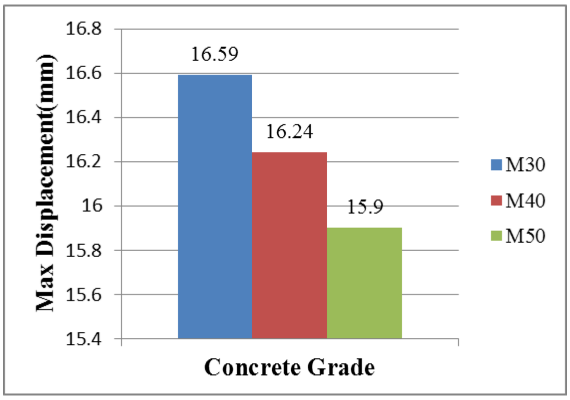

Fig. 10. Max Deformation for various grades of concrete

F. Effect on Charge Weight

Of all the three parameter, the amount of explosives plays a predominant role on the destruction of column. More the amount of TNT is used; more the columns are vulnerable to the damage. Form the graph it is evident that the lateral ties with lesser space has showed less deformation when compared with the lateral ties with more spacing.

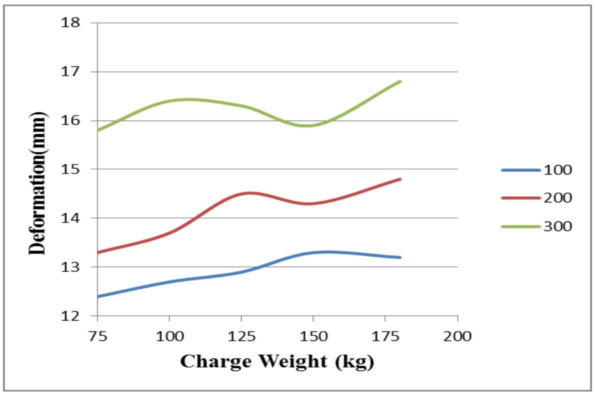

Fig. 11. Max Deformation for vaious charge weights

G. *Effect on Spacing of Transverse Bar*

The purpose of lateral reinforcement is to prevent the buckling of column. During the blasting maximum damage occurs to the lateral ties and hence this affects the proper functioning of the same. The spacing of lateral reinforcement was kept as 100mm, 200mm, 300mm. When the lateral ties were kept closer, it gave more confinement and this prevents the displacement of the column. Here the spacing of 100mm worked better compared to the spacing of 200mm and 300mm.

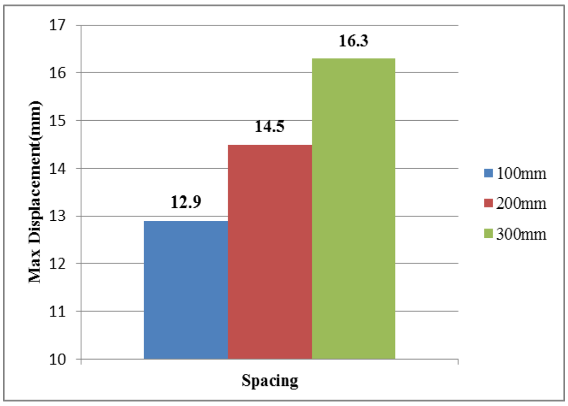

Fig. 12. Max Displacement for various spacing of lateral ties

III. RESULTS AND DISCUSSION

From various combinations of parameters which includes spacing of lateral ties, grade of concrete and charge weight, a total of 45 cases had been executed. Of that, the column with the spacing of 100mm modeled with grade of concrete M50 and bombarded with the charge weight of 75kg exhibited lesser deformation. Among the three parameters considered, the spacing of lateral ties plays a significant role in the deformation of column. The closer spacing of ties resulted in the less deformation of the column. The increase in the grade of concrete did not yield much effect on the column. By increasing the grade of concrete from M30 to M50, the deformation decreased by only 1mm. Also the increase in charge weight leads to catastrophic failure and therefore more deformation was reported.

IV. CONCLUSION

- Use of Seismic Detailing techniques can significantly reduce the reduce the degree of direct blast induced damage.
- Load carrying capacity decreases with increase in charge weight.
- Grade of Concrete is increased from 30MPa to 50MPa and its corresponding displacement is decreased by 0.7mm for 300mm Spacing Transverse bar.It shows that the displacement increases as the spacing increases.
- Transverse bar spacing is increased from 100mm to 300mm and its corresponding displacement is increased by 3.4mm for M40 grade concrete@75 kg of TNT
- Charge weight is increased from 75kg to 180 kg of TNT and its corresponding displacement increased by 1mm.
- Among the three parameters Transverse bar spacing have major influence on damage.

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